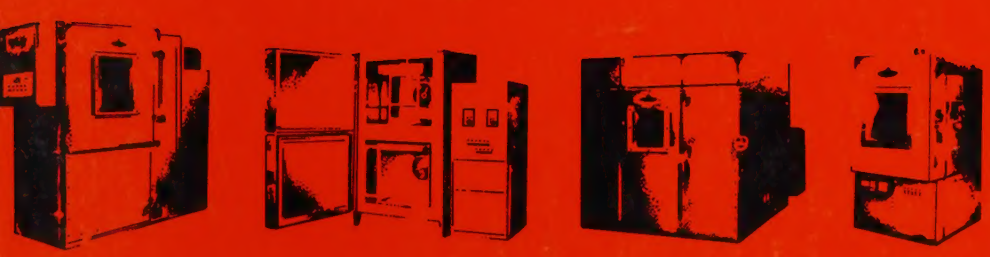
MODEL 013008

THERMOTRON

VSTR.
LAB.

INSTRUCTION MANUAL



IN THE BEGINNING
THERE IS PRICE

IN THE END,
THERE IS COST

As a businessman, you know there are certain things you would never buy on the basis of price alone.

And probably, way up near the top of that list are environmental facilities.

Thermotron doesn't sell test chambers on price. We sell on the value of experience, services, quality and performance.

These services and performance are designed to help you prevent and control losses of production and products; and losses are what determine ultimate cost.

That's why we don't just ask for the chance to QUOTE on your business. We want the chance to show you what we can be worth in the long run.

27 November 1972

USER MANUAL

SLOPE GENERATOR

Assembly No. 013008, 013009

Dwgs: 470217
470224
470229
470233

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Introduction

The Slope Generator is essentially a Set Point transition rate controller.

The device is intended for use in applications which involve automatic control of some variable at one or more operating points. The purpose of the Slope Generator is to control the rate at which the variable moves towards the operating point (at start up, for instance) or to control the timing of a transition from one operating point to another.

Representative applications involve kilns, heat-treatment facilities, Reliability/Environmental Test Chambers, etc. The device can be scaled as necessary to adapt it to virtually any application.

The Slope Generator was first designed and manufactured by Thermotron to accommodate one of our own requirements related to the programming of temperature test chambers. By virtue of this background, the application which is currently most frequently encountered involves temperature transition rate control within an operating range of -125°F. to +375°F. Since this application is most common, it is referred to quite frequently in this manual, whenever an example is needed to help clarify the discussion. When the user's application is different, the points made in the text will still apply, even if the examples cited are not directly applicable.

Introduction (Continued)

The new Slope Generator system is functionally similar to its predecessor, Model 013001, but there any similarity ends. Model 013001, the original Slope Generator, was designed for a specific application, and was difficult to adapt to other applications. The new equipment is designed with application versatility in mind, and offers the user a greater range of flexibility, with a higher degree of precision. The new equipment is not directly interchangeable with Model 013001.

General Description

The purpose of the Slope Generator system is to control the transition rate of a process variable, either during start-up and shut-down operations, or during transitions from one set point to another.

In most applications, the Slope Generator intervenes between the set point system and the process controller. In such systems, a 0v/+5vdc signal is used to represent the process variable in terms of 0%/100% of span. For instance, in a temperature control system having a range of -125°F to +375°F, the 0v level is analogous to -125°F (0%) and the +5vdc level represents +375°F (100%).

The set point signals provided at the input of the Slope Generator must always have this 0v/5vdc relationship. Likewise, the output of the Slope Generator will always have this same relationship. The output may be attenuated, however, for compatibility with controllers which accept low-level set point signals. This can be accomplished with a simple resistor network, as explained in Section IV of this manual.

In operation, the Slope Generator acts like a slow "voltage follower" circuit. Whenever its input level changes, its output level will also change in the same direction, but at a slower rate. The output of the Slope Generator changes in a linear

General Description (Continued)

manner, at a rate which is preset during calibration or set by the operator by means of front panel controls. The output transition continues at this rate until the output is driven to the same value as the input. At this point, the transition ends and the output is held equal to the input, until the input is changed once again.

The set point information which is provided to the input of the Slope Generator may be derived from either a manual or programmed set point station. The input impedance of the Slope Generator is typically 70 Meg ohms, so the unit presents no significant load on the set point system. The general input requirements include (1) low electrical "noise", (2) accurate 0v/+5vdc calibration and (3) the input rate of change must exceed the rate of change which the Slope Generator is required to produce.

The output transition rate of the Slope Generator is adjustable over a range of zero to ±10,000 mv/minute. However, the output voltage range of the unit is limited to -.4vdc/+5.1vdc. The output is incremented or decremented at half-second intervals, such that it takes the form of a "staircase wave" rather than a purely linear ramp. In practice, transition rates as low as ±1mv/min. can be set with a reasonable degree of accuracy. Slower transitions are also possible, but require special calibration and involve a higher degree of uncertainty.

General Description (Continued)

The Slope Generator system has two major components. The basic Slope Generator Assembly 013008 contains a completely functional circuit system. The Slope Generator Indicator/Control Station provides an interface between the operator and the Slope Generator. The Indicator/Control Station includes an analog meter which can be set to measure or monitor either the input or the output of the Slope Generator. This unit also includes various mode switches, upscale and downscale digital rate adjustments, plus transition mode indicator lights. By means of the mode switches, it is possible to transfer the input directly to the output, thereby bypassing the Slope Generator. Where transition rate programming is used, these switches also allow operator intervention during programmed operation. In addition, "fast-set" and "stop and hold" functions can also be achieved.

In certain applications, operator capabilities may not be required, or desired. In these applications, the basic Slope Generator Assembly is used without its mating Indicator/Control Assembly. In such installations, the operating mode of the Slope Generator is established by means of "softwired" connections at its terminal blocks, and the unit is calibrated to provide preset upscale and downscale transition rates, as required by the application.

As mentioned above, the transiton rates may also be varied by a remote transition rate programmer. Programmed systems, also,

General Description (Continued)

may or may not include the Indicator/Control Station, depending upon the requirements of the application.

The basic Slope Generator Assembly is packaged as a simple "black-box" system component measuring approximately 12" x 6" x 2". This unit may be mounted at any convenient location, and preferably at a location which is relatively free of dust, vibration and temperature variation.

The Indicator/Control Station is a completely self-contained unit measuring approximately 10" x 5" x 2". This unit is designed for mounting on the operator's control panel and includes a three-foot cable for interconnecting it with the Slope Generator.

Specifications

Parameter	Min	Typ(1)	Max	Units
Input/Output Offset		±4.0	±15	mv
Hysteresis		±2.0	±7.5	mv
Roc Accuracy	±1.0	±0.7		%Roc
. . . plus	±5.0	±0.5		mv/min
Roc Stability	±5.0	±1.5		%Roc
. . . plus	±2.5	± .075		mv/min
Input Impedance	20	70		Meg Ω
Output Impedance			1.0	ohm
Output Loading			10.0	mA
Input Signal Range(3)	0		5.0	vdc
Output Voltage Limits(3)	-0.4		+5.1	vdc
Transition Rate Range(2)	0		±10,000	mv/min
Operating Temperature Range	0	25	55	°C
Power Requirements:				
Voltage:	100	115	130	vac
Frequency:	50		60	Hz

(1) Typical specs allow ambient temperature variations of ±5°C.

(2) See rated accuracy and stability for uncertainties affecting ultra-slow operation.

(3) Input and output are short circuit proof, but may be damaged if connected to potentials in excess of ±12 volts.

Installation and Wiring

New units should always be inspected, inside as well as outside, prior to installation. Look for evidence of abuse during shipping and handling, such as bent or broken parts, loose parts, broken wires, missing fasteners, etc.

Covers may be removed by pressing in gently at both ends to release the detents, then pulling the cover up and out of the tracks in the chassis.

Mounting information is provided in drawing 470229 for both the Slope Generator (013008) and the Slope Generator Indicator/ Control Station (013009).

The Slope Generator may be mounted in any position. However, the mounting method should provide for convenience during wiring, calibration and subsequent maintenance. Be sure to allow sufficient room for cover removal and access to terminal blocks and calibration adjustments.

The Slope Generator should be mounted in an area which is relatively free of electrical interference (noise) and vibration. Noise suppression for near-by motors, power contactors, etc., may be worthy of consideration.

To mount the Slope Generator, remove its cover and temporarily remove the circuit board assembly from the chassis (six screws). Then mount the chassis at the desired location, replace the

circuit board assembly and the cover.

NOTE

In mounting the chassis, use only #6 pan head or binding head screws. Inspect this installation carefully to assure that the heads of the mounting screws are at least 1/8-inch below the bottom surface of the circuit board, and cannot cause short circuits.

The Indicator/Control Station, if used, must be located within three feet of the Slope Generator, and should be located at some point which will be convenient to the equipment operator. This unit includes an analog meter, and should be mounted vertically with respect to the meter scale. Inclinations of up to 45 degrees are permissible, but in such cases the calibration of the meter should be verified prior to placing the equipment into operation. It is not normally necessary to remove the cover of this unit during installation, wiring or calibration, and rear access may not be required if the unit can be removed from its mounting location from its front side.

Wiring information for a "typical" process control application is provided in Drawing 470224. In this case, the Indicator/Control Station is used with the Slope Generator, and the application involves set point transition rate control for a temperature controller.

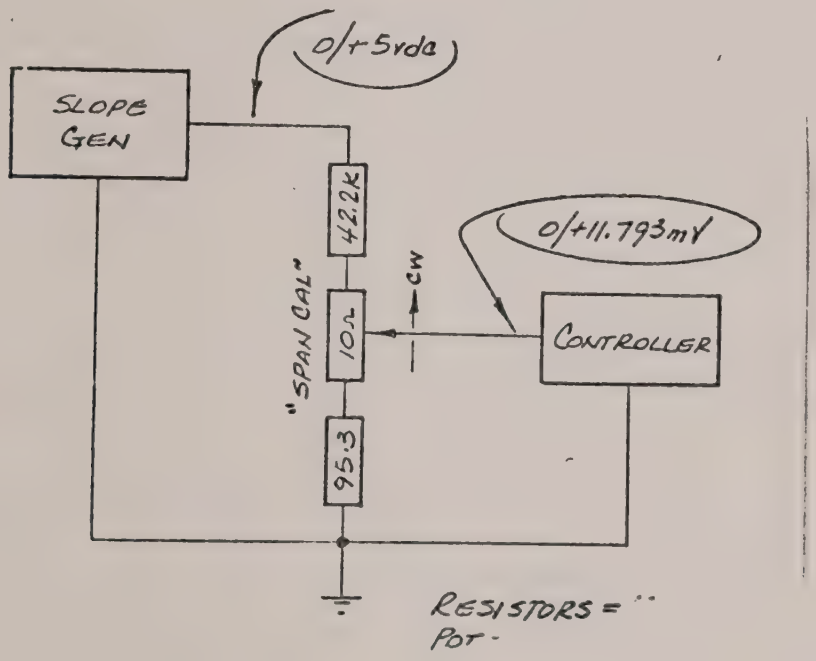
Installation and Wiring (Continued)

As shown in Drawing 470224, wiring involves connecting 115vac, 50/60 Hz power to TB1, input and output cabling at TB2, and connecting the Indicator/Control Station's cable at TB3 and TB4. The power line connected to the Slope Generator should be one which is relatively free of electrical transients.

The input signal is 0 - 5vdc, as is the output signal. Hence, the compatibility of the input source and the output load should be verified prior to making these connections. (See Specifications.) If it is necessary to attenuate the output of the Slope Generator to make it compatible with controllers or other loads which accept low level inputs, a simple voltage divider may suffice, and is easy to make using resistors. In general, the resistor values should be kept as low as possible in the interest of minimizing the possible effects of noise and loading, but the total series resistance presented to the output of the Slope Generator must not be less than 500Ω. If the attenuator is to be adjustable for the sake of precision, it should be recognized that the "wiper shift" for most trimpots is about equal to their resolution. Hence, the range of adjustment should be kept as small as absolutely possible so that shock and vibration will not destroy the calibration.

Temperature controllers which have a range of -125°F to +375°F, and which use a type T thermocouple, deal with input signals (from the sensor) which have a span of 11.793mv. Some

such controllers accept an identical set point signal, which is then compared directly against their input. A schematic diagram of an attenuator which would be suitable for this application is provided here as an example.



Whenever the Indicator/Control Station is used, the wiring will be as shown, regardless of the application.

When the application in question is not compatible with Drawing 470224, refer to Section XII of the User's Manual which was provided with the Slope Generator, for more specific information.

If this information is not available, it is possible to "work out" the wiring requirements for TB3 and TB4 by referring to the schematic diagram, Drawing 470217 ("wiring information" table). In some applications, the functions which are normally provided by the Indicator/Control Station may be permanently predetermined by using jumper wires at TB3 and TB4, and the potentiometers R18 and R22 may be located on the circuit board and preset for one specific output transition rate. In other applications, some but not all of the remote components may be used instead of the Indicator/Control Station. In every case, it is always necessary to provide for the functions of S1, S2, R18 and R22. The functions of S3, CR7 and CR9 may be treated as optional.

If desired, Thermotron Customer Service may be called upon for applications assistance and will be happy to provide specific wiring information for your particular application.

PRELIMINARY INFORMATION
(Subject to Change)

Operation

In applications where the Slope Generator is not equipped with its mating Indicator/Control Station, its operation is fully automatic. In such cases, the unit is specially wired and calibrated to provide a specified transition rate, and no operator intervention is required.

Where the Slope Generator Indicator/Control Station is used, the requirements imposed upon the operator consist only of selecting the desired mode of operation and adjusting the transition rates to the desired values. In order to accomplish this, operators should familiarize themselves with the function of each switch and adjustment on the control station. Towards this end, the following description is provided.

The Slope Generator Indicator/Control Station is equipped with the following:

1. An input/output indicator meter.
2. Upscale/downscale indicator lites.
3. Upscale/downscale transition rate adjustments.
4. A rate scale multiplier switch.
5. An indicator-output mode switch.
6. A manual-remote mode switch.

Operation (Continued)

The calibration of the meter is dependent upon the application. The -125°F to +375°F calibration is typical for temperature control systems. However, the scale may be calibrated in any system of engineering units which is significant for the application in question. In all other aspects, the Indicator/Control Station is the same in all applications.

The indicating meter provides a means of measuring or monitoring either the input or the output of the Slope Generator System, and is controlled by the indicator-output mode switch, S2. Since many systems of engineering units are non-linear, an analog meter is used. Since the meter scale can be graduated in a non-linear manner, a direct reading indicator can be provided for any system. In addition, the analog indicator provides a "relative" indication (i.e., indicates the input or output level with relation to 0% and 100%) which can be interpreted quickly at a glance.

The indicator-output mode switch has three positions, which are marked "NORMAL", "EinCK", and "BYPASS". In the normal position, the Slope Generator provides its normal transition rate control function and the meter indicates the output value. In the EinCK position, the meter is connected to the input of the Slope Generator without otherwise disturbing the normal function of the unit. This switch position allows the operator to check

Operation (Continued)

the input value whenever desired and is useful when pre-setting programmed input values. When the switch is moved to the Bypass position, the normal output of the Slope Generator is pre-empted and the input is connected directly to the output. In bypass operation, however, the Slope Generator continues to operate in the normal manner, even though it is not providing the output. Obviously, the meter indication provided during bypass operation is indicative of both the input and output value.

The upscale/downscale transition rate adjustment knobs are used in conjunction with the rate scale multiplier switch to establish the desired transition rate setting. The adjustment dials have a mechanical 3-digit read-out (000 to 999) and the scale switch has three positions which are labeled "X10", "X1", and "X.1".

The Slope Generator uses a 0v/+5v electrical analog to represent the programmed variable in a form which electrical circuitry can manipulate. For instance, in a typical temperature control system:

0v/+5vdc = -125°F/+375°F

This means that when the output is zero, a temperature of -125°F is called for, and if the output is +5vdc, a temperature of +375°F should result. Likewise, an output of +2.5vdc would be analogous to a temperature of about +125°F, if the temperature measuring system is linear.

Operation (Continued)

For any application, the analog can also be expressed in terms of "% of span":

0v/+5vdc = 0%/100% of span

For instance:

0v/+5vdc = 0%/100% = -125°F/+375°F

By the same token, the transition rate can also be expressed by any one of these conventions:

±volts/unit time

±% /unit time

±°F /unit time

By properly selecting the values of a few internal components, the Slope Generator can be configurated so that its digital transition rate dials are direct-reading in practically any system of engineering units.

Since the temperature programming application is the most frequently encountered, the following explanation is based upon that application. If the application in question is different, the pertinent system variations are summarized in the last section of this manual.

In temperature programming applications, the range of -125°F to +375°F is typically involved and the temperature transition rate is usually specified in terms of ±°F/minute average. The term "average" is used to account for the fact that the Slope Generator provides linear electrical transitions from one point to another on a temperature scale which may or may not be linear. If a thermocouple or RTD sensor is used in the temperature measuring system,

Operations (Continued)

without linearization, then the actual temperature transition rate will vary, depending upon the operating points. This potential error affects both the actual instantaneous and average transition rates. Since linearization is expensive, "typical" systems are not so equipped, and methods of compensating for this limitation are given below.

For the typical temperature system, dual scaling of the transition rate controls is provided, as follows:

"mv/Minute" Scale		
Switch Position	Dial Position	Rate
X10mv	999+1	±10vdc/Minute
X1mv	999+1	±1vdc/Minute
X.1mv	999+1	±.1vdc/Minute

and:

"°F/Minute Ave" Scale		
Switch Position	Dial Position	Rate
X1°F	999+1	±1000°F/Minute
X.1°F	999+1	±100°F/Minute
X.01°F	999+1	±10°F/Minute

The "999+1" position of the digital dials represents their maximum clockwise position. The dials are continuously adjustable from "000" to 1000 ("999+1"), and the transition rate

varies accordingly, from zero to the maximums shown above. For instance, for a switch position of "X1mv/X.1°F and a dial setting of "100", the resulting transition rate will be ±100mv/min = ±10°F/min ave.

Note that this same transition rate would be produced by a switch position of "X.1mv/X.01°F" with a dial setting of "999+1". This would be the better choice of the two possible settings, since the transition rate dials are somewhat more accurate at the higher settings. Therefore, as a rule of thumb, always use the highest possible dial setting and the lowest possible multiplier (switch position).

Sensor Non-Linearity Correction

In order to produce accurate transition rates in terms of °F/min.ave. in non-linearized systems, proceed as follows:

1. Define T1 in % span on the basis of thermocouple millivolts (mv) or RTD ohms (R):

   RTD: % span at T1 = $\frac{RT1-R0\%}{R100\%-R0\%}$

   T/C: % span at T1 = $\frac{mvT1-mv0\%}{mv100\%-mv0\%}$

2. In a similar manner, define T2 in % span.

3. Find the difference in % span, between T1 and T2.

4. Multiply this number times ±5.0 volts in order to define the transition in terms of the 0v/+5vdc analog.

5. Divide this number by the desired total transition time, in minutes, to find the correct setting in terms of "mv/min".

6. Set the multiplier switch and transiton rate dial(s) accordingly, in terms of "mv/min", ignoring the "°F/min" scaling.

7. By virtue of these settings, the Slope Generator will accurately execute a given transition in the "total transition time" specified in Step 5 above. Hence, the transition rate in terms of "°F/min ave" will be correct regardless of the position of T1 and T2 on the non-linear scale.

The above procedure should be used when (1) the temperature measuring system is non-linear and (2) precision transition rate accuracy is desired. In cases where the starting point (T1) and the end point (T2) lie on opposite sides of the 50% span point, good accuracy can result by setting "°F/min ave" directly; in other cases, the resulting accuracy may suffice if precision is not required. Naturally, if the measuring system is linear, precision accuracy will result from "°F/min" settings with no requirement for calculating corrective settings as per the above procedure.

Separate upscale and downscale transition rate adjustments are provided on the Indicator/Control Station. These may be set

independently, except that the scale multiplier switch applies to both dials simultaneously. A little arrow adjacent to either dial identifies which is which, plus the dials are color coded; orange being the upscale dial and green being the downscale dial.

Indicator lights associated with the rate dials (LED's) display the mode of the Slope Generator circuitry. When a transition is being executed, the light which is adjacent to the appropriate dial will flash ON and OFF at a one-second rate, which serves to indicate the direction and speed of the transition. When no transition is in progress, these lights remain OFF.

The "manual" - "remote" mode switch allows the operator to take command of the transition rate away from a remote transition rate programmer. If such a programmer is used in the system, a separate set of instructions are provided to cover its operation.

In the absence of a transition rate programmer, this switch can be wired to provide either one of the following functions:

(1) "fastset"

(2) "stop and hold"

Operations (Continued)

The "fast set" option is achieved by jumpering terminals on the back of the Indicator/Control Station:

connect 1 to 2

and 4 to 5

This function allows the Slope Generator to be driven rapidly to any setting by switching the manual/remote switch to "Remote" and the multiplier switch to "X10". The resulting rate will be ±10,000mv/minute, which will drive the Slope Generator over its entire range in 30 seconds.

Note that switching to "Remote" produces the same result as if both rate dials were set to "1000". As delivered from the factory, all Indicator/Control Stations will be wired in this manner.

The "stop and hold" option allows the operator to stop and hold the temperature setting at any point along a transition. This option is achieved by reconnecting the jumper wires on the back of the Indicator/Control Station:

connect 2 to 3

and 3 to 4

After this has been done, moving this switch to the "Remote" position will place the Slope Generator into a memory mode. In this mode, the Slope Generator circuit freezes its output and will hold that instantaneous value indefinitely, subject to drift, so long as this switch remains in the "Remote" position.

Operations (Continued)

In certain circumstances, this function can be quite useful. However, the output of the Slope Generator, in the memory mode, can drift upscale or downscale at a rate of up to ±30mv/hour. In the typical temperature application (-125°F to +375°F), this can amount to ±72°F/day.

Therefore, users availing themselves with this option should recognize that a potential safety hazard exists, especially when the application involves process control. The attendant safety hazard depends upon the nature of the application. In general, this switch should never be left in the "Remote" position (memory mode) for extended periods of time without operator supervision.

In order to help assure against inadvertent tripping, all three switches on the Indicator/Control Station are locking types. To change the switch position, it is first necessary to pull the toggle forward before it can be moved to a new position.

Simplified Circuit Analysis

When a capacitor is connected across the terminals of a battery, electrons will rush out of the negative terminal of the battery and into the capacitor. At the same time, electrons rush out of the opposite end of the capacitor and into the positive terminal of the battery. This happens because there is an excess of electrons at the (-) side of the battery and a deficiency of electrons at its (+) side; current resulting when the capacitor is connected is an attempt to resolve this imbalance.

Capacitors are constructed by separating two conductive elements (plates) with a very good insulator (dielectric), such that current is not able to flow through the unit. In the above experiment, current rushes into one side of the capacitor, and out the other side, only because charges seek equal distribution within the available "real estate". Once that excess electrons on the "negative"side and the deficiency of electrons on the "positive"side are equally distributed, then the current in the circuit is zero.

At this time, if the capacitor is disconnected and then connected across a voltmeter, one would find that it now carries a charge equal to that of the battery.

If its leads are now shorted together, the excess electrons on its negative side will rush thru the shorted leads to its positive side, where there was a deficiency of electrons. After

this happens, each atom in the conductive material will have been restored to equilibrium, each having its proper number of orbiting electrons, and a voltmeter measurement will indicate that there remains no charge when the short is removed.

The magnitude of the charge and discharge current in these experiments depends upon the size of the capacitor. If its plates are large, crowded electrons at the (-)side of the battery see wide open spaces to spread out into and a lot of them make a dash for it. Also, the (+) side of the battery is able to pull a lot of electrons out of the other side of the capacitor before they begin to be missed.

Capacitor sizes are expressed in farads. If a total charging current of 628 quadrillion electrons produces a charge of exactly one volt, then the capacitor is said to have a capacitance of one farad.

For convenience, 628 quadrillion electrons can be treated as a lot, and called one coulomb. It so happens that an ampere of current is defined as 628 quadrillion electrons, or one coulomb, passing a given point in a circuit in one second.

For another experiment, suppose that we connect one farad capacitor across a current source that puts out one ampere. A voltmeter connected across the capacitor would show that its charge increases at a rate of one volt per second. This is

the result of the fact that the current involved is one coulomb per second, and each coulomb produces a charge of one volt across the capacitor.

From this we can derive a formula which will permit us to calculate valves for any circuit such as this:

$$\Delta E_c = \frac{I}{C}$$

where:

ΔE_c = Voltage change across the capacitor in "volts per second"

I = Current, in "amperes"

C = Capacitance, in "farads"

By re-arranging this formula:

$$I = C \times \Delta E_c$$

and:

$$C = \frac{I}{\Delta E_c}$$

From the first formula, one can see that ΔE_c varies in direct proportion to I. In other words, if I is doubled, ΔE_c is doubled; if I is reduced by half, ΔE_c will be cut in half.

It is also apparent that the capacitor will charge and discharge at a constant, or linear, rate, since ΔE_c is simply expressed in volts per second.

As another experiment, suppose that we pour boiling hot water into a drinking glass which has been pre-chilled in a freezer. A broken glass results, by virtue of thermal shock.

Simplified Circuit Analysis (Continued)

The fractures are produced by high stress, which develops as the glass attempts to expand too rapidly, due to the sudden application of heat in large quantities. The stress develops because some parts of the glass are able to expand at a faster rate than others, due either to differences in mass or the uneven application of heat. Naturally, the glass would otherwise be able to withstand such temperature variations.

Now suppose we have the following problem. We must design a temperature test chamber for a certain electronic product. The product is to be tested by cycling the chamber temperature between -65°F and +160°F, holding at each temperature until the temperature of the product has completely restabilized. The temperature transition rate between the "soak levels" is to be at least ±9°F/minute on the average, and the product will be subjected to this cyclic exercise for several days. The electronic product, itself, contains thousands of parts, made of hundreds of different materials. Through careful design, the problems which could occur due to normal expansion and contraction with temperature, have been eliminated. However, we are less certain about the possible effects of fast temperature changes, since it is impossible to design this product such that all of its parts will restabilize to a new temperature at the same rate.

In view of this uncertainty, it would be unwise to exceed the stress level imposed by the ±9°F/minute specification.

Simplified Circuit Analysis (Continued)

If "tailor-made" to suit this specific test requirement, the test chamber can be designed so that its average temperature transition rate is about ±9°F/minute, with the product inside. This simplifies control requirements, since we can provide two set point adjustments for the temperature controller and simply switch from one to the other with a timer, permitting the chamber to "free run" between the -65°F and +160°F set points. The disadvantage is that if anything in this system changes, the transition rate calibration will be lost. In other words, this chamber might not be suitable for testing smaller products and would not be capable of testing larger products.

As an alternative, we could actually control the temperature transitions, such that they occur at a rate of ±9°F/minute, by programming the controller's set point on a continuous basis, instead of simply switching it between the two extremes.

Ideally, the programmer should be accurate, simple, and easy to program. This precludes the use of cam followers, curve followers, digital to analog converters, and the like.

Using what we know about capacitors, we can satisfy these requirements. First, we'll select a controller which accepts a voltage signal as its set point input. The unit selected has a range of -125°F to +375°F, and accepts a zero to +5vdc set point input.

Simplified Circuit Anaylsis (Continued)

Next, for the set point adjustment, we'll connect two potentiometers across a +5vdc power supply, so that their wiper voltage varies from 0v (-125°F) to +5v (+375°F) as they are turned in a clockwise direction. As a precision readout, these pots can be fitted with a digital counting dial which varies from "000" to "999" and can be interpreted as "% of span".

Then we can provide a capacitor, a bi-directional and adjustable constant current source, and a control circuit to control the direction of the constant current.

Finally, we'll connect the controller input across the capacitor, and the set point pots to the constant current control circuit through time clock contacts.

In operation, the time clock will connect one of the set points to the constant current control circuit. This circuit will control the direction of the current in such a manner that the capacitor is charged, or discharged, towards the set point voltage level. When the capacitor voltage and the set point voltage are equal, this circuit will turn OFF the constant current source. Since the controller sees the capacitor voltage as its set point signal, we can program the slope of temperature transitions by adjusting the constant current level. The programming task is then completed by adjusting the time clocks so that it switches the set point pots alternately in and out at the correct times.

Simplified Circuit Analysis (Continued)

In designing the "Slope Generator", we'll have to consider three factors:

$$\Delta E_c = \frac{I}{C}$$

Since the controller uses a 0v/+5v analog for its -125°F to +375°F temperature range, a ±10 millivolt change at its set point input is analogous to ±1°F. Since we want to produce a ±9°F/minute slope, ΔE_c will have to be about ±90mv/minute, or ±1.5mv/second.

This is a small ΔE_c. By inspecting the above formula, we can see that ΔE_c will be small when C is large and I is small.

For good accuracy, we can assume that the capacitor used will have to be a very good one. A review of various catalogues indicates that 10 microfarads is about the practical limit for ultra-high quality capacitors.

Having determined the values of ΔE_c and C, we can calculate the value of the constant current required:

$$\pm I = \pm \Delta E_c \times C$$
$$= \pm 1.5\text{mv} \times 10 \text{ ufd}$$
$$= \pm 15 \text{ nanoamperes}$$
$$(= \pm .000000015 \text{ amperes})$$

This is a very low level current. With practical, inexpensive components, it is not likely that we could build a current source which would be reliable at these low levels.

Simplified Circuit Analysis (Continued)

Going back to the formula, we originally assumed that I was continuous. On second look, if I is switched ON for only a fraction of each second, then ΔE_c will be proportionately reduced. If I is ON for only a thousandth of each second, then ΔE_c will be one thousandth of its normal value. On the other hand, for the same vlue of ΔE_c, switching I ON and OFF in this manner permits I to be 1000 times greater than its normal value. Hence, we can revise this formula somewhat:

$$\Delta E_c = \frac{It}{C}$$

where t = the length of time that I is ON during each second, in seconds.

Assuming that we'll permit the constant current to flow for only one millisecond per second, the constant current level becomes:

$$I = \frac{\Delta Ec \times C}{t}$$

$$= \frac{1.5mv \times 10mfc}{.001}$$

$$= 15 \text{ microamperes}$$

$$(= .000015 \text{ amperes})$$

This is a more practicable current value. Hence, to complete our set point programmer we'll add a chopper in series with the constant current, which permits current to flow during only one thousandth of each second.

A simplified block diagram of the Slope Generator is shown here. The circuit includes a clock which produces a reference

frequency of one cycle per second. Two adjustable constant current sources provide a positive current to charge the capacitor, or a negative current to discharge it, at an accurately calibrated rate. The upscale-downscale control circuit compares the input set point signal with the output signal, and operates the two switch circuits as necessary to drive the output towards the input. The control circuit also performs the "chopper" function which was discussed above.

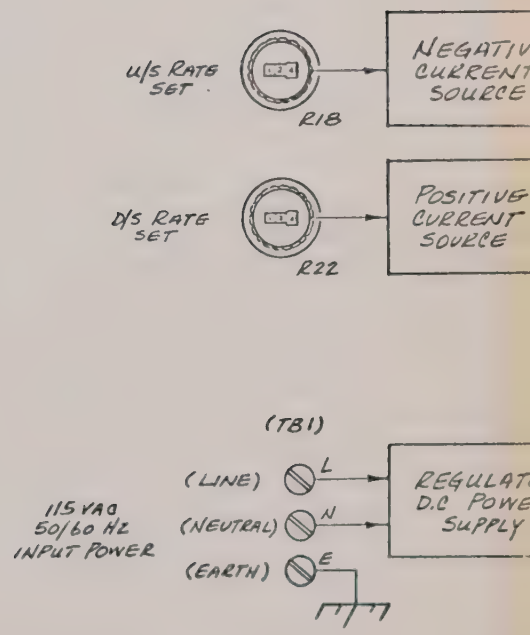
When the system includes an Indicator/Control Station, a switch is provided which allows the input signal to be connected directly to the controller, bypassing the Slope Generator. Another switch changes the chopper operation such that the constant current "ON" time is either 1ms, 10ms, or 100ms, which expands the range of the unit in three steps:

X.1 = 0 - 100 mv/min

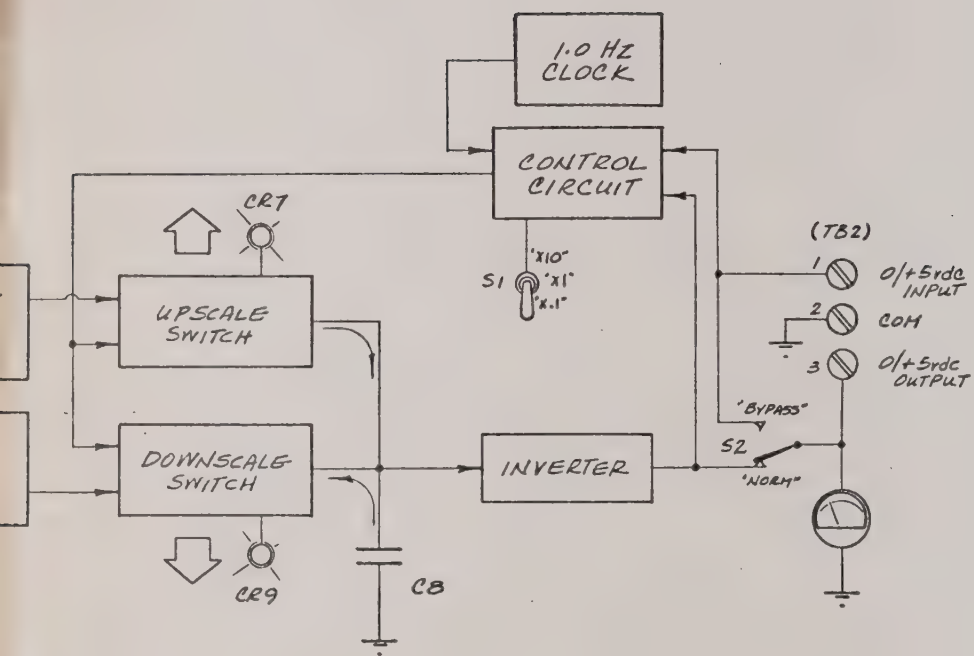
X1 = 0 - 1000mv/min

X10 = 0 - 10,000mv/min

This switch is used in conjunction with the constant current adjustments which are equipped with 3-digit 10-turn dials. An analog meter is also provided, by means of which the input set point signal or the output signal can be measured, or monitored. Finally, flashing LED indicators are provided, which indicate whether the output is being driven upscale, downscale, or if it is stabilized.



THERMOTRON
CORPORATION
HOLLAND, MICHIGAN 49423



Notes

1. Output R.O.C. is adjustable in terms of ±mV/Min useing R18-R22 dials and S1 scale multiplier switch.
2. Indicator lites CR7 & CR9 fiash at a rate of 1.0 Hz to indicate upscale or downscale output transitions.

CHANGES	DATE	BY	CHK'D	NO	CHANGES	DATE	BY	CHK'D

TOLERANCE

SCALE

MATERIAL

FINISH

DRAWN BY SKINNER DATE 29 Oct 72

CHECKED BY DATE

RELEASED BY DATE

DESCRIPTION

SLOPE GENERATOR (TM)
BLOCK DIAGRAM
(SIMPLIFIED)

REF: 013008 & 013009

470233

(TM) TRADE MARK THERMOTRON CORPORATION

Simplified Circuit Analysis (Continued)

As mentioned in the Introduction of this manual, the Slope Generator was originally designed by Thermotron to accom-modate some of our own temperature programming requirements. In fact, the above test chamber application is the one for which this equipment was designed. Since this has, by far, proven to be the typical application for the Slope Generator, it is used as a base for various discussions in this manual.

From the preceeding information in this section, however, it should be clear that the Slope Generator can be adapted to practically any process control application where transition rate control is required or desired. The input/output range of the equipment is simply 0v/+5vdc, and the transition rate range is ±0/±10,000mv per minute. Obviously, the 5vdc analog can be applied to any system of engineering units (temperature, pressure, motor speed, flow rate, vacuum, liquid level, humidity, etc.), and to any range. The equipment is also suited to applications other than process control (lighting control, special effects, test equipment, etc.). The only thing which "customizes" the Slope Generator for any particular application is the graphics used on the Indicator/Control Panel. A new meter scale and special legends can be printed as appropriate for any application, but otherwise the equipment is usually identical and the information presented in this manual remains valid for all users. (Any significant variations are noted in Section XII of the manuals delivered with the equipment.) In some cases, where neither adjustability or indication are required, the Slope Generator may be used without the Indicator/Control Station.

Simplified Circuit Analysis (Continued)

In the case of the -125°F to +375°F temperature application, the meter is calibrated with this temperature scale, using the curve of either a copper vs. constantan (Type T) thermocouple or a platinum resistance thermometer, depending upon which one of these electrical temperature sensors is used to provide the necessary temperature measurement for the controller. (Platinum RTD's are sometimes used where precision accuracy is required, otherwise thermocouples offer good accuracy, reliability, and interchangeability at much less cost.) Both of these scales have an equivalent °C calibration, and 10% markers. Both of these scales are non-linear, unless the system also includes a device which converts the non-linear response of the temperature sensor into a linear temperature measurement.

An electronic temperature controller actually controls electricity, not temperature. Such devices simply manipulate heat as necessary to set thermocouple millivolts or RTD ohms to a preset value.

At -125°F, the response of the thermocouple is about ±.017mv/°F. At +375°F, its response is about ±.030mv/°F. The total response of this sensor over this range is about 11.793mv, so its average response is about ±.024mv/°F.

This low level signal is multiplied by a factor of 425 within the controller, in order to boost if to the 0v/+5vdc analog level. Hence, the response at analog levels is about:

Simplified Circuit Analysis (Continued)

±7.225mv/°F near -125°F

±10mv/°F average

±12.750mv/°F near +375°F

Since the output of the Slope Generator varies at a linear rate in terms of mv/minute, it is obviously impossible to generate a linear slope in terms of °F/minute . . . unless a linearizing signal conditioner is added to the system between the thermocouple and the controller. Since this involves a cost of a few hundred dollars, it usually isn't done unless linear temperature transitions are mandatory.

In the absence of a linearizer, if we desired to perform transitions at a rate of ±1°F/minute, we could set the Slope Generator for a rate of ±10mv/minute, the average response of the temperature measuring system. The result, in terms of °F/minute, would be:

±1.43°F/min near -125°F

±1.0°F/min near 50% of span

±0.785°F/min near +375°F

This same discrepancy occurs when a platinum sensor is used, although to a lesser extent since the platinum element has a much more linear response. The fact is that in control applications the transition rate can be expressed in direct engineering units only if the measuring system is linear. Otherwise, it must be specified in average terms (e.g., ±°F/min ave) or in mv/min.

Simplified Circuit Analysis (Continued)

A method of setting the Slope Generator so as to provide precision transition times in conjunction with non-linear measuring systems is given in Section V of this manual.

Careful readers may have observed that the output of the Slope Generator is not truly linear so far as time is concerned. The fact is that when it produces an upscale or downscale set point transition, it does so by incrementing or decrementing the output voltage in small steps. This is due to the operation of the constant current choppers which were discussed above. If we were to record the output on a wide-chart recorder, the result would be a line which is linear in terms of mv/minute, but which otherwise looks like a staircase. Circuits which produce this kind of output are frequently referred to "staircase-wave generators", for obvious reasons, and are frequently used in digital-to-analog (or visa versa) converters. The unique aspect of the Slope Generator is that it is probably the "slowest" staircase-wave generator of all, yet it still provides a reasonable degree of accuracy.

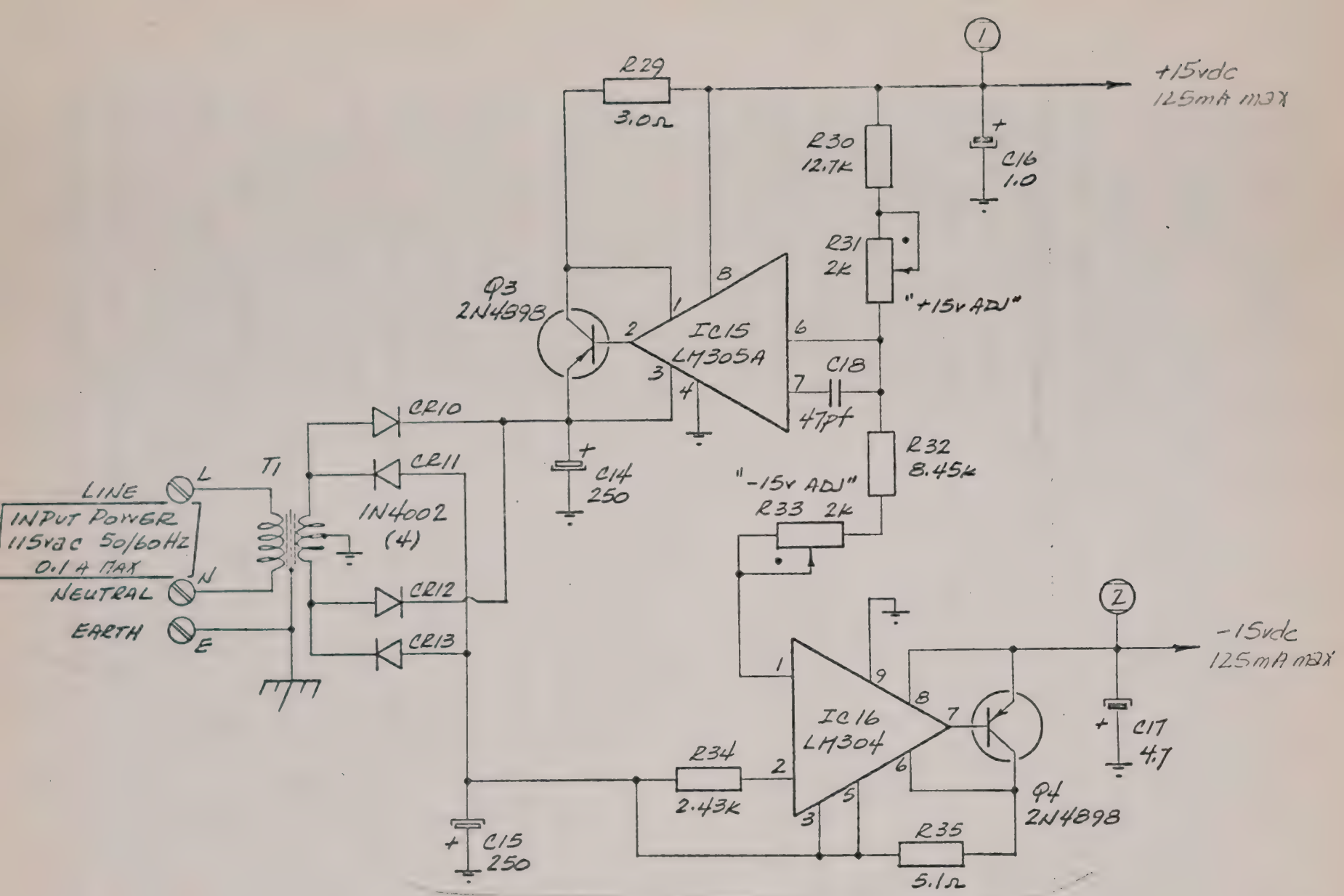
Since the choppers actually operate at a 2 Hz rate, the amplitude of each step is:

$$E_{step} = \frac{\text{Roc Setting in mv/min}}{120}$$

Hence, for a setting of 100 mv/min (± 10°F/min), the amplitude of each step is about 0.833mv (±0.08°F), and two such steps occur during each second.

Simplified Circuit Analysis (Continued)

In process control applications, the slow response of the system being controlled will, as a rule, integrate these small steps in such a manner that they are completely "filtered out", and the end result is linear. In certain non-process, fast response applications, these steps might be a significant factor in evaluating the potential performance of the system.


R29
3.0Ω
+15vdc
125mA max
R30
12.7k
C16
1.0
R31
2k
"+15v ADJ"
Q3
2N4898
IC15
LM305A
C18
47pf
R32
8.45k
"-15v ADJ"
R33 2k
CR10
CR11
IN4002
(4)
CR12
CR13
C14
250
T1
LINE
INPUT POWER
115vac 50/60Hz
0.1A MAX
NEUTRAL
EARTH
L
N
E
IC16
LM304
R34
2.43k
C15
250
Q4
2N4898
R35
5.1Ω
C17
4.7
-15vdc
125mA max

Power Supply

This section of the handbook provides a detailed technical analysis of the Slope Generator circuitry. This analysis is provided for maintenance technicians, who will be responsible for maintaining the equipment in good working order and for correcting failures if and when they occur. This section is written with reference to the schematic diagram, drawing number 470217. That drawing should be referred to while studying this section of the manual. As a prerequisite to understanding the information presented in this section, the reader should first read sections I, II, III, V and VI.

(Insert Power Supply Diagram)

In any electronic device, a good power supply is essential to accurate, reliable operation. The Slope Generator circuit includes a bilateral 15 vdc power supply (+15vdc and -15vdc). Since these dc supply voltages are used to provide reference voltages, as well as power for the circuit, both are equipped with precision voltage regulators.

Transformer T1, diodes CR10 thru CR13, capacitors C14 and C15, form a bilateral, full-wave, unregulated dc power supply. These circuits convert the 115vac line power to ±30vdc levels, which appear at the top of C14 (+30vdc) and the top of C15 (-30vdc). These two dc levels are unregulated and will vary with the input line voltage, and the load current required by the circuit. Under

Functional Analysis (Continued)

Power Supply (Continued)

extreme conditions, they may vary by as much as ±10v, although during normal operation the variation will not usually exceed ±2 volts. It might be noticed that this circuit actually consists of two conventional full-wave supplies which share a common transformer. This transformer, T1, has a 3:1 step-down ratio and includes a "faraday shield" to prevent noise on the 115vac power line from being fed into the Slope Generator via capacitive coupling across the windings. This shield should always be connected to a good earth (waterpipe) ground.

IC15 and its associated components comprise the +15vdc regulator, while IC16 and its adjacent components form the -15vdc regulator. These two circuits operate on a semi-interdependant basis. Resistor R32 marks the dividing line between the two regulator circuits, and is a shared component.

The references for the two voltage regulators are included within the integrated circuits. IC16, an integrated negative voltage regulator, provides a precision constant current reference between its Pins 1 and 2. The magnitude of this current is fixed at about 1.0mA by R34. The path of this current is through R34, IC16, Pin 2 to Pin 1, R33, R32, R31 and R30. IC15, an integrated positive voltage regulator, includes a precision, temperature compensated constant voltage reference, the operating point of which is about +1.7vdc.

Functional Analysis (Continued)

Power Supply (Continued)

Pin 6 is the feedback terminal of IC15. In operation, IC15 will adjust the output voltage level as necessary to set Pin 6 at +1.7vdc, which balances this circuit with respect to its constant voltage reference. If R31 is set at 600Ω, then the voltage dropped across R30 and R31 in conjunction with the 1.0mA reference current will be 13.3vdc. Under these conditions, the cutput will be driven to +15vdc in order to set Pin 6 of IC15 at +1.7vdc.

The operation of the negative regulator, IC16, is somewhat different. In this case, the output is set by the value of resistance connected between Pin 1 of IC16 and ground. The scaling relationship is about 2vdc per kΩ. In other words, if a 7.5kΩ resistor was connected between Pin 1 and ground, the output voltage would be -15vdc.

Obviously, resistors R33 and R32 are not connected to ground, and it would appear that they would not meet the 7.5kΩ requirement even if they were. What is not obvious, however, is the fact that a virtual ground occurs within R32. Since the current through R32 is 1.0mA, the voltage drop across it is 8.45vdc. Since Pin 6 of IC15 is at +1.7vdc, then there must be a point within R32 where the voltage with respect to ground is zero volts. Measuring from this (inaccessible) point to the top of R32 would provide an indication of +1.7vdc. And from this point to the bottom of R32, the measurement would be -6.75 vdc. Hence, the effective resistance between this virtual ground and R33 must be about

Functional Analysis (Continued)

Power Supply (Continued)

6.75kΩ. Therefore, if R33 is adjusted to 750Ω, the total resistance from IC16, Pin 1, to the virtual ground will be 7.5kΩ, and the output of the negative regulator will be (2v/kΩ) -15vdc.

Both regulator circuits act by adjusting the load current so that the voltage drop across the load circuitry is 15 volts. In typical operation, the load currents are about ±45mA. Since the voltage across the regulators is about ±15 volts, the power dissipated by each of these circuits is (P=IE) about 675mW. Since this dissipation meets or exceeds the absolute maximum for the integrated circuits, booster transistors Q3 and Q4 are incorporated to handle the load current. This improves the regulation of each circuit by a factor which is about equal to the current gain of the booster transistors. In addition, handling the load outside of the IC's means that their temperature, and therefore, their reference circuits, will remain much more stable.

Both regulators are equipped with a current limiting feature which protects them, and to some extent the load circuitry, from overloads. The current limits are set at ±125mA by R29 (for the +15v supply) and R35 (for the -15v supply). In operation, the voltage drops across these resistors are monitored by their associated regulator circuits. The regulator circuits act as necessary to prevent these voltage drops from exceeding prescribed maximums (375mv for R29 and 635mv for R35).

Functional Analysis (Continued)

Power Supply (Continued)

Capacitor C18 is provided to compensate for the high frequency characteristics of IC15. IC16 includes its own internal compensation capacitor. These capacitors prevent high frequency oscillation within the integrated regulator circuits. Capacitors C16 and C17 are used to compensate for an interaction between the output circuitry of the IC's and the input of the booster transistors which can also produce high frequency oscillation. These capacitors also improve the transient response of the regulators. Since the instability is inclined to occur at high frequencies, low inductance (solid tantalum) capacitors must be used. Most other types have a high equivalent series resistance at high frequencies, and are not effective.

SHORT COURSE ON 'OP AMPS'

As can be seen on the schematic diagram, the linear circuitry consists mainly of operational amplifiers in I. C. form. It is a fact of life today that, no matter how much a designer would like to 'be original', a given function can usually be achieved more readily and more economically by using these prefabricated building blocks. The results, in terms of performance and reliability, will generally be equal or better than anything that can be achieved with an original design using discrete components. It is predicted that during this decade I. C. sales will triple, while the sales volume of discrete components will be reduced by half.

At the time of this writing we find ourselves nearing the middle of this trend, which started in the early 1960's.

Progress and change presents demands for continuing education. Unfortunately, since hindsight is always better than foresight, it is difficult to predict what knowledge will be required in the future, and one often finds that he has a lot of catching up to do in order to 'stay current.'

The following is provided as a ready reference for those who have fallen behind, and may provide some basic answers in a moment of need. Only the rudaments are covered however, and the maintenance technician would do well to expand his knowledge of these devices further by reading any one of several good books on the subject.

As indicated in the schematic diagrams, the op amp is treated as a single replaceable part of the circuit. What happens inside of this device? At the maintenance level, the details of its inner workings will not usually be required in order to judge whether or not the device is functioning properly. As a general rule, the integrated op amp can be treated as a 'black box' which

+ is an amplifier, a differential voltage amp
+ whose input impedance is infinite
+ whose output impedance is zero
+ whose open loop gain is infinite
+ whose power supply drain is insignificant

The pin connections shown on the schematic diagrams are, more or less, standard among all types of op amps.

As shown, these devices require bilateral power inputs (i. e., both a positive and a negative power supply). The negative supply is connected to pin 4, and the positive supply is connected to pin 7. In most applications the (+) and (–) power levels will be equal voltages, differing only in polarity. *Reversing the power connections to the device will usually result in its destruction.*

A small compensation capacitor is usually connected between pins 1 and 8 in order to stabilize the operation of the circuit. These devices are inherently excellent RF amplifiers, and in practical applications it is impossible to eliminate stray capacitances. Since the basic requirements for any self excited feedback oscillator are (1) an amplifier, (2) feedback in the proper phase and amplitude and (3) some sort of energy storage device to sustain oscillations and determine frequency, any practical op amp circuit is a potential oscillator. In the abscence of the compensation capacitor these circuits will almost certainly oscillate at a frequency of 1 - 5 megahertz whenever their output is not at the positive or negative limit (saturation).

The op amp has two input terminals. Pin 2 is the *'inverting'* input, and pin 3 is the *'non-inverting'* input. Signals applied to pin 2 will be reproduced at the output with a greater amplitude and opposite phase. Signals applied to pin 3 will be reproduced as a magnified replica of the input (increased amplitude—same phase).

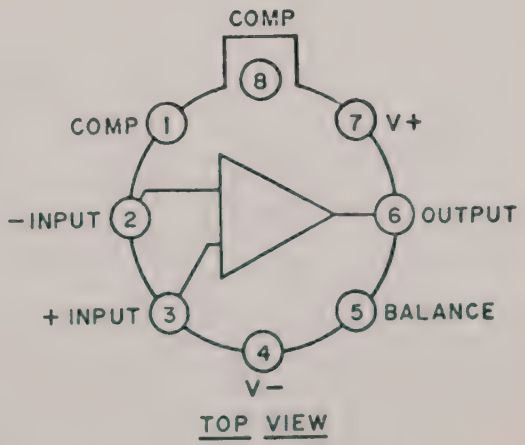
The output of the op amp is provided at pin 6. The output voltage can swing both positive and negative with respect to ground, and to within about 1.0 vdc of the supply potentials at saturation.

If the potentials at pin 2 and pin 3 are equal and of the same polarity, the output will be balanced at ϕvdc with respect to ground. In practical devices some small offset usually exists because of imperfections. This is known as the *'input offset voltage'* (the amount by which the inputs must be offset from perfect equality in order to bring the output to ϕvdc).

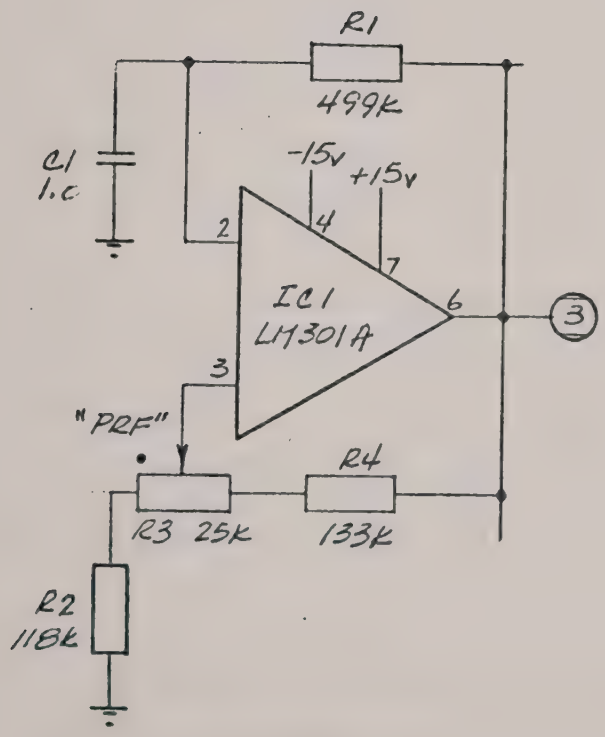
If the potential at pin 2 is greater (more positive) than that at pin 3, the output will be negative with respect to ground. Conversely, if the voltage at pin 3 is increased in the positive direction, the output will move in a positive direction.

How much the output changes for a given input variation depends on the gain of the circuit. Unless limited by the addition of external networks, the open loop large signal voltage gain may be as high as 300,000. This can be reduced to any lesser value by external feedback networks, while a non-inverting voltage follower (gain = 1) can be achieved simply by connecting pin 2 to pin 6, using pin 3 as the input.

These devices generally have integral overload protection at both their input and output terminals. This means that shorting these terminals to either supply or ground will not usually not harm the device. If, however, these terminals are shorted to a potential exceeding the supply levels (e. g., if the power supplies have been turned off) destruction of the device is likely.



TOP VIEW


R1
499k
C1
1.c
-15v
+15v
2
4
7
IC1
LM301A
6
3
3
"PRF"
R4
R3 25k
133k
R2
118k

1 Hz Multivibrator

- DIAGRAM HERE -

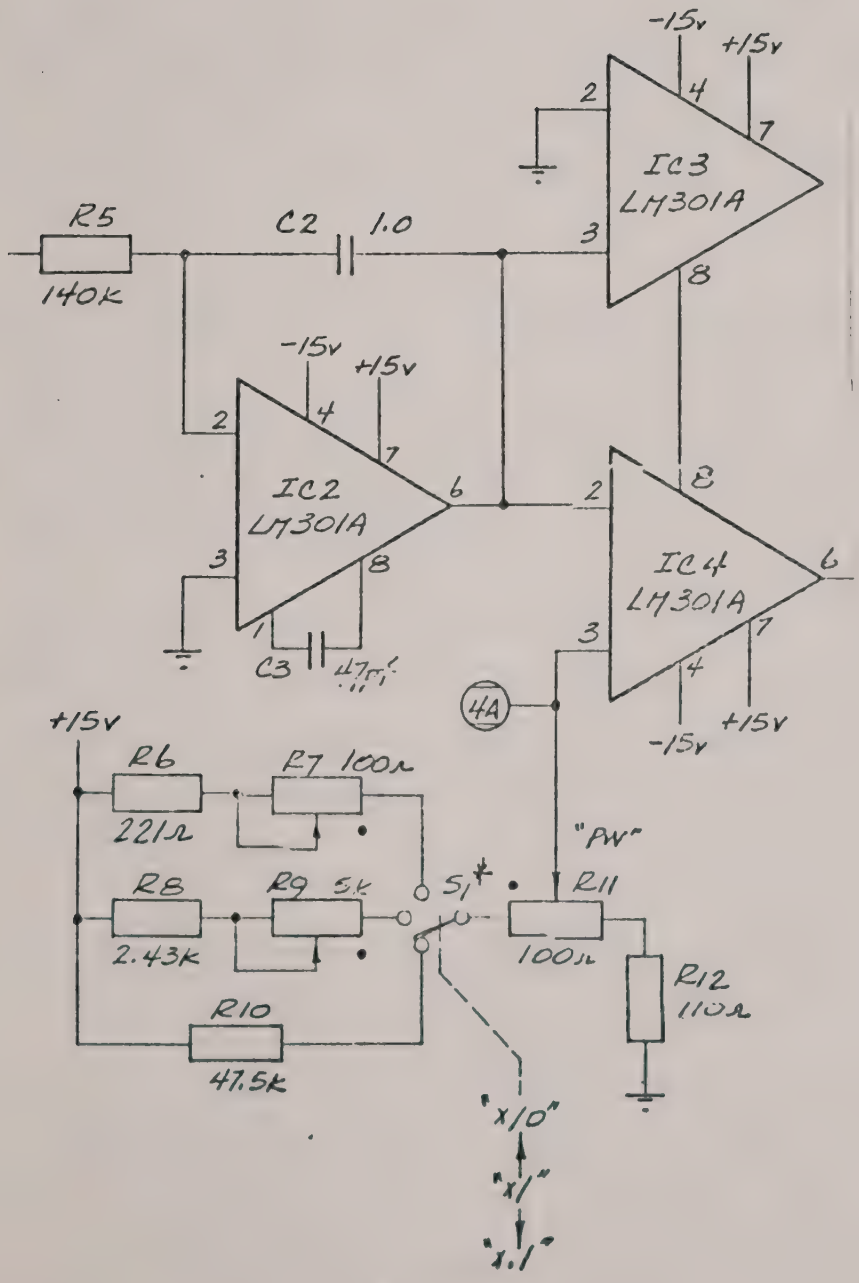
The "clock"circuit, IC1, provides a one cycle per second square wave, which is used as the time base of the Slope Generator.

Capacitor C1 and resistor R1 have an Rc time constant (T=RC) of about 500 milliseconds. In operation, IC1 switches alternately between its positive and negative saturation limits, which typically equal ±14.25 volts.

A reduced replica of this output square wave is developed by the adjustable voltage divider formed by R2, R3, and R4, and connected to the non-inverting input of the op amp. The potential connected to Pin 3 will be about +6.56v during the positive half cycle, and -6.56v during the negative half cycle.

When IC1 switches to the positive half cycle, C1 charges in a positive direction through R1. When the charge on C1 reaches +6.56v (the potential connected to Pin 3) the output of the IC will switch to its negative saturation limit, about -14.25 volts. At this instant, the potential across R1 is (-14.25v + 6.56v) about 20.81 volts.

C1 now begins to charge in the negative direction. In one time constant (.5 sec) C1 will charge through about 63% of the potential across R1, or through about 13.12 volts. Since the capacitor started its negative charge cycle from +6.56v, after .5 second it will have achieved a new level of (+6.56 - 13.12) -6.56 volts. During the negative half cycle, this same potential is present at Pin 3. Hence, when the charge on the capacitor reaches this level, the output of the IC will switch back to


-15v
+15v
IC3
LM301A
R5
140k
C2
1.0
IC2
LM301A
C3
.47mf
IC4
LM301A
4A
+15v
R6
221Ω
R7 100Ω
R8
2.43k
R9 5k
S1
"PW"
R11
100Ω
R12
110Ω
R10
47.5k
"x10"
"x1"
"x.1"

1 Hz Multivibrator

+14.25 volts. In .5 second C1 will have returned to the +6.56v level, whereupon the output switches to -14.25v once again.

As is evident, this circuit will alternate between its positive and negative saturation limits continuously, producing a square wave output having an amplitude of about ±14 volts, and a frequency of 1.0 Hz, which may be precisely calibrated by means of R3.

Pulse Forming Circuits (DIAGRAM HERE)

The pulse forming circuits, IC2, 3 and 4, provide the accurately calibrated dc voltage pulses which are applied to the constant current choppers, Q1 and Q2.

The input to these circuits is provided by the clock circuit, IC1. The time required for IC1 to slew between its negative and positive saturation limits is about 150 microseconds. Hence, the 1 Hz square wave provided to the pulse forming circuit has sharp leading and trailing edges.

The purpose of IC2 is to soften these edges so that they will have a slope of ±100 volts per second.

The input square wave is applied to R5. Since op amps strive to balance their inputs (Pins 2 and 3), and since Pin 3 of IC2 is grounded, the output of IC2 (Pin 6) will vary as necessary to cause the entire input signal to be dropped across R5. Since the input square alternates between +14v and -14v, IC2 will produce currents of +.1mA and -.1mA in R5, in response to the input. Note that the level of this current is constant, and that it is bidirectional.

Pulse Forming Circuits (Continued)

Note also that capacitor C2 is in the current path.

When a capacitor is charged by a constant current, the charge rate, in volts per second, is:

$$\Delta E_c = \frac{I}{C}$$

By substituting values into this equation, it can be demonstrated that C2 will charge, bidirectionally, at a rate of 100volts/second.

Pin 2 of IC2 is a virtual ground, since its potential is (for all practical purposes) zero volts. Thus, when the clock signal at the input is +14 volts, current flows from Pin 6 of IC2 towards R5. This means that C2 (Pin 6) charges negative with respect to Pin 2. Hence, for a positive input, IC2 produces a negative-going output, and visa versa.

The output of IC2 takes the form of a "mesa wave". Since IC2 actually slews between its ±14v saturation limits at a rate of 100v/sec, the output during one cycle slews downscale during 280ms, rests downscale 220 ms, slews upscale during 280 ms and rests upscale 220 ms. C3 is the compensating capacitor for IC2, which controls the high frequency behavior of the circuit.

IC3 and IC4 are combined to form a double-ended limit detector, which in this case is used as a pulse forming circuit. The input to this circuit is the "mesa wave" generated by IC2, and is connected to IC3, Pin 3 and IC4, Pin 2.

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

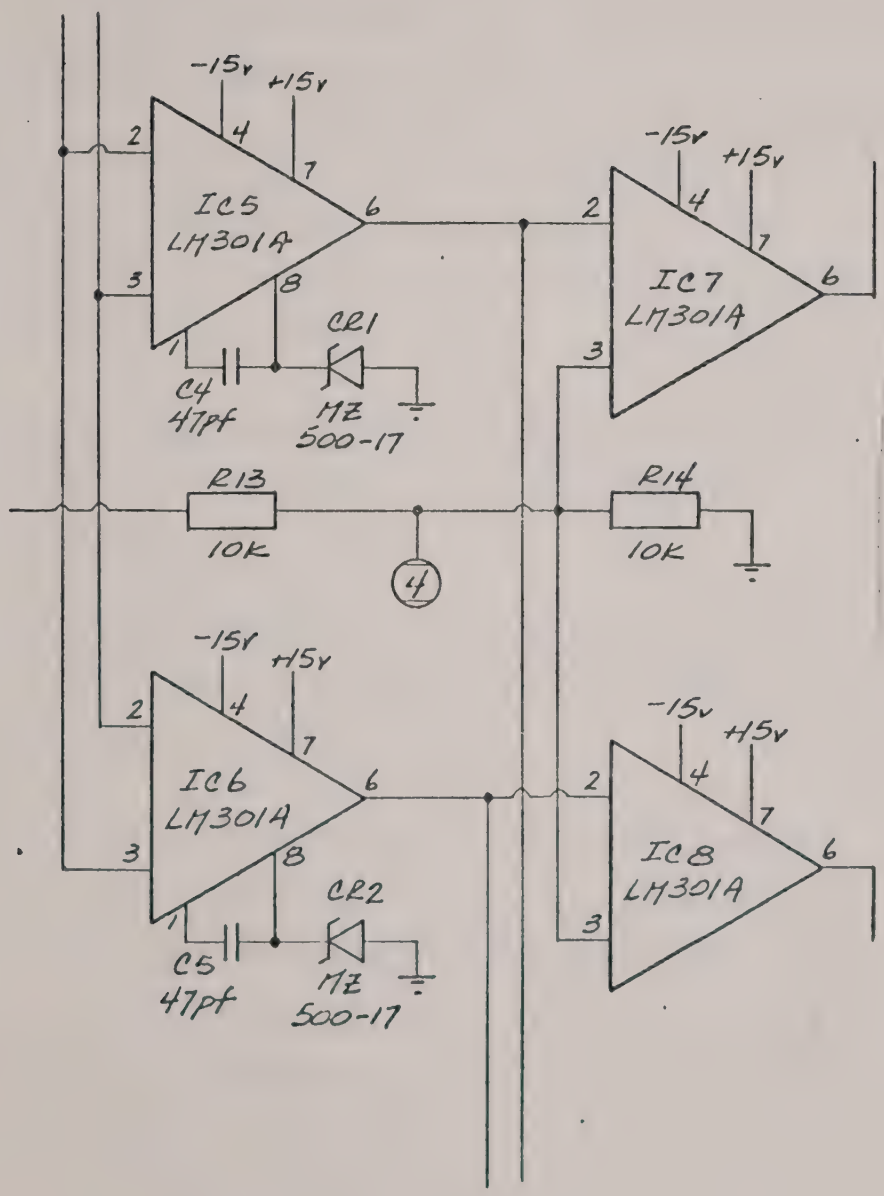
The operation of this circuit is controlled by two reference voltages, called the "lower trip point" (LTP) and the upper trip point (UTP). The LTP is zero volts, and is established by grounding the reference input of IC3, Pin 2. The UTP is variable. Deriving from the network consisting of R6 through R12, including S1, the UTP is connected to the reference input of IC4, Pin 3.

During operation, when the amplitude of the mesa wave is less than zero volts (negative), the output of IC3 will be at its negative saturation limit. During this same time, the output of IC4 would be at its positive saturation limit, except that by virtue of the common Pin 8 connections, the output of IC4 is clamped at the same level as the output of IC3, about -14 volts, and cannot move more positive.

When the amplitude of the mesa wave slews upscale, the output of IC3 switches to its positive saturation limit at the instant that mesa wave crosses the zero volt LTP. This removes the negative clamp, allowing the output of IC4 to swing to its positive limit.

Continuing to slew upscale, the mesa wave eventually crosses the positive UTP, at which instant the output of IC4 will switch to its negative limit.

This action produces a pulse at the output of IC4, Pin 6, whose width depends upon the slew rate of the input and the UTP setting.


-15v
+15v
IC5
LM301A
IC7
LM301A
IC6
LM301A
IC8
LM301A
CR1
MZ
500-17
C4
47pf
CR2
MZ
500-17
C5
47pf
R13
10K
R14
10K
4

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

A second pulse will be generated as the mesa wave slews back downscale, with IC4 being turned ON at the UTP, then clamped OFF as the mesa wave drops below the LTP.

Since the mesa wave slew rate is ±100v/sec, a 0.5ms pulse width could be achieved by setting the UTP at (.0005 x 100) +50mv. This is accomplished by switching S1 to the "x.1mv" posititon and adjusting R11 as necessary.

Likewise, 5ms pulses can be produced by setting the UTP at 500 mv. This is accomplished by adjusting R9 while S1 is in the "x1mv" position.

Finally, 50ms pulses can be generated by setting the UTP at +5.0 volts. This is done with S1 in the "x10mv" position by adjusting R7.

As can be seen from the above, the pulse forming circuitry provides an output whose pulse recurrence frequency (PRF) is 2.0 pulses per second, and whose pulse width (PW) can be set for 0.5, 5.0, or 50ms, by means of S1. The PRF is established by the clock frequency. The significance of the above pulse widths will be presented below.

(DIAGRAM)

The comparator and gate circuits, IC5 through IC8, control the application of these precision pulses to the chopper transistors, Q1 and Q2.

Functional Analysis (Continued)

Pulse Forming Circuits (Continues)

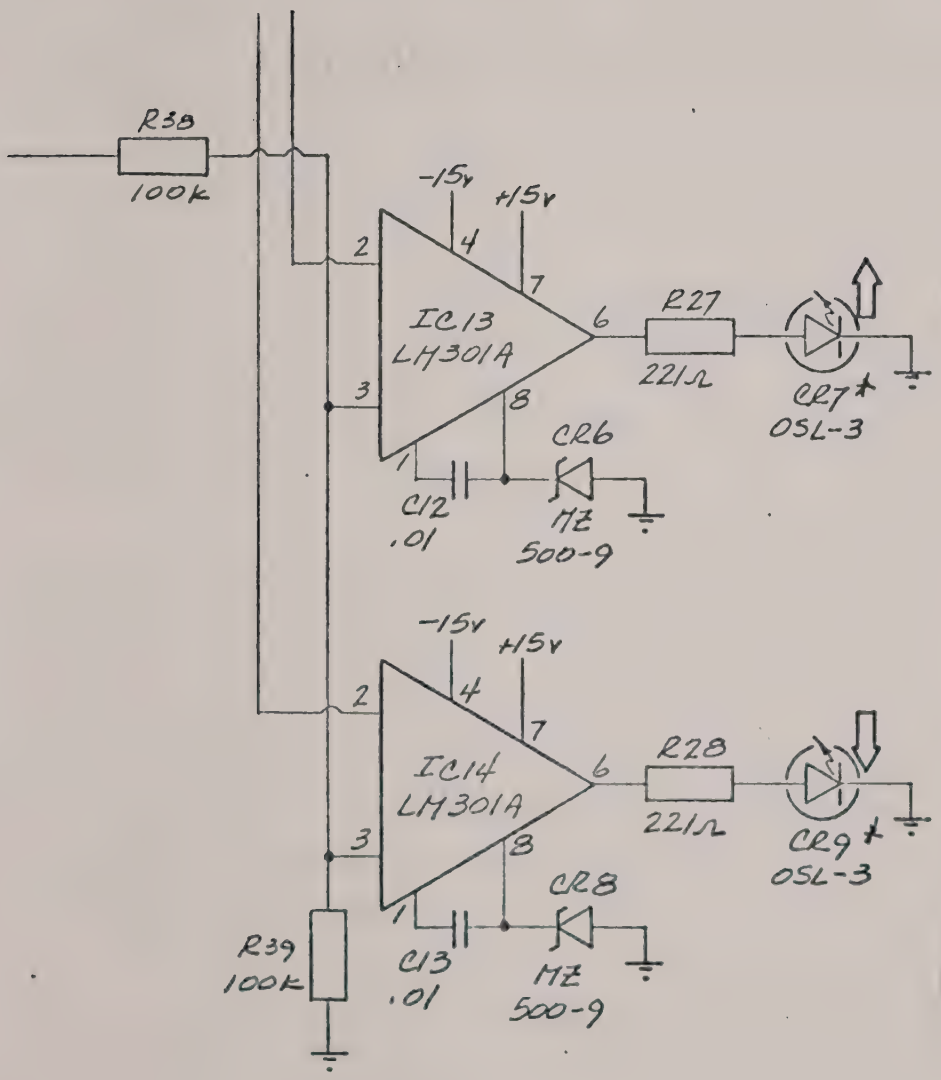
The precision pulses are fed to gate circuits IC7 and IC8, through a voltage divider composed of R13 and R14. Due to the voltage divider, the pulses provided at Pin 3 of IC7 and IC8 will have an OFF amplitude of about -7 volts and an ON amplitude of about +7 volts.

The inverting inputs of IC7 and IC8 (Pin 2) are controlled, respectively, by comparator circuits IC5 and IC6.

The comparator circuits compare the output set point voltage (from IC11 - 6) with the input set point signal (from IC17 - 6). At IC5, the ESP in signal (0-5vdc) is connected to Pin 2 and the ESP out signal is connected to Pin 3. When the output signal is less than the input signal, Pin 3 will be negative with respect to Pin 2, and the output of this circuit (Pin 6) will therefore be at its low limit. Due to clamping diode CR1, the "low limit" for this circuit is about -0.7 volts.

Hence, for this condition (output lower than input) Pin 2 of IC7 will be set at about -0.7 volt. Since Pin 3 of IC7 is pulsed by the ±7 volt timing signals, the output of IC7 (Pin 6) will swing between its saturation limits, ±14 volts. This output will have the same phase, pulse with, frequency and amplitude as the pulse signal produced at the output of IC4.

When the output signal is greater than the input signal, Pin 3 of IC5 will be positive with respect to Pin 2. The output


R38
100k
-15v
+15v
2
4
7
IC13
LM301A
6
3
8
1
R27
221Ω
CR7
OSL-3
C12
.01
CR6
MZ
500-9
-15v
+15v
2
4
7
IC14
LM301A
6
3
8
1
R28
221Ω
CR9
OSL-3
CR8
R39
100k
C13
.01
MZ
500-9

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

of IC5 will then be at its positive limit, which is set at about +11v by zener clamping diode, CR1. Pin 2 of IC7 will also be at this same potential. Since the pulse signal connected to Pin 3 of IC7 varies between ±7 volts, Pin 3 can never become positive with respect to Pin 2, and the output of IC7 will rest at its negative saturation limit, -14 volts.

In effect then, IC5 and IC7 act like a simple switch which connects the output pulses at Pin 6 of IC4 to the input of the upscale chopper, Q1, whenever the output set point signal is less than the input set point signal.

Comparator circuit IC6 and gate circuit IC8 are identical to IC5 and IC7, except that the inputs of IC6 are reversed with respect to IC5. This simply reverses the operation of these circuits. Specifically, IC6 and IC8 act like a simple switch which connects the output pulses at Pin 6 of IC4 to the input of the downscale chopper, Q2, whenever the output signal is higher than the input set point signal.

(DIAGRAM)

Functional Analysis (Continued)

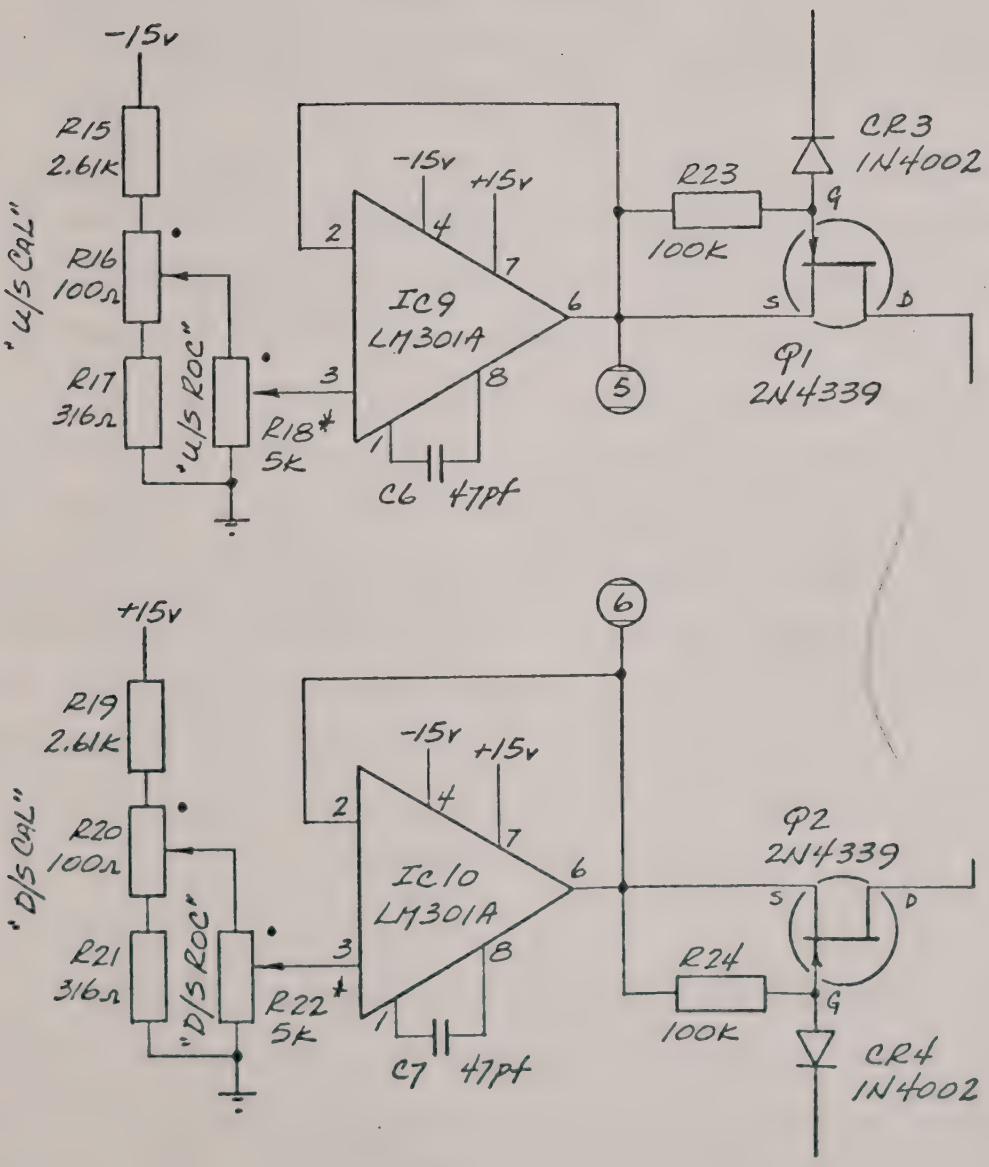
Pulse Forming Circuits (Continued)

The logical output signals of IC5 and IC6 are also used to operate the upscale and downscale indicator lights. As shown, these two outputs are connected to Pin 2 of the IC13 and IC14 (respectively), the indicator driver circuits. Pin 3 of both drivers is provided with a 1 Hz, ±7volt square wave from clock circuit IC1, through the voltage divider composed of R38 and R39.

When the slope generator is driving its output set point signal in the upscale direction, the output of IC5 will be at its -0.7 volt setting. Therefore, Pin 2 of IC13 will also be at -0.7 volt for this condition. The ±7 volts, 1 Hz signal applied to Pin 3 of IC13 will, therefore, cause the output Pin 6, to switch alternately between +5.1 volts and -0.7 volt, the clamped limits established by zener clamping diode CR6. When the output switches to +5.1 volts, a current of about 15 mA is drawn through the LED upscale indicator CR7 and R27. This causes CR7 to emit a visible quantity of light. When the output swings to its low limit, -0.7 volt, CR7 is reverse biased, and no current flows in the output circuit, so CR7 will be dark.

When the Slope Generator output is either stabilized or driving downscale, the output of IC5 will be about +12 volts. Since the 1 Hz signal at Pin 3 of IC13 is ±7 volts, Pin 3 of IC13 will always be negative with respect to Pin 2, and the output at Pin 6 will remain at -0.7 volt. Hence, CR7 will remain OFF.

The downscale driver and indicator circuit, which involves IC14 and CR9, is identical to the upscale circuit, except that its controlling input is provided from the downscale comparator IC6.


-15v
R15
2.61k
R16
100Ω
R17
316Ω
"U/S CAL"
"U/S ROC"
R18*
5k
C6 47pf
IC9
LM301A
-15v
+15v
2
4
7
6
3
8
1
5
R23
100k
CR3
IN4002
Q1
2N4339
G
S
D
+15v
R19
2.61k
R20
100Ω
R21
316Ω
"D/S CAL"
"D/S ROC"
R22*
5k
C7 47pf
IC10
LM301A
6
Q2
2N4339
R24
100k
CR4
IN4002

Pulse Forming Circuits (Continued)

As has been shown, the upscale/downscale indicators operate only during periods when the Slope Generator is actually in the "slope" mode, and these lights flash ON and OFF at a rate of one cycle per second. CR7 and CR9 are a part of the Slope Generator Indicator/Control Station (013009). Where this item is not included in the system, similar LED's may be connected for remote indication, or for test purposes. These outputs will not provide sufficient power to drive incandescent lamps. Capacitors C4, C5, C12 and C13 are compensation capacitors which control the high frequency characteristics of their respective op amp. C12 and C13 are sized so as to "soften" the turn ON and turn OFF of IC13 and IC14, which handle relatively large output currents. This helps to prevent these circuits from generating bursts of high frequency noise during switching operation. Resistors R27 and R28 establish the current through CR7 and CR8, at about 15 mA, which assures optimum LED brightness and long life.

(Diagram here)

IC9 and IC10 are precision voltage reference circuits. IC9 provides a negative reference voltage which is adjustable over the range of 0v to -1.666v by means of R18. IC10 provides a complimentary positive reference voltage, which is adjustable over the range of 0v to +1.666v by means of R22.

Pulse Forming Circuits (Continued)

R18 and R22, the "Slope Rate" adjustments, are normally a part of the Slope Generator Indicator/Control Station (013009), and are equipped with precision three-digit numerical read-out dials. Where the 013009 Indicator/Control Station is not used, R18 and R22 are 25-turn trimming potentiometers mounted on the Slope Generator circuit board.

IC9 and IC10 are wired as voltage followers. These circuits prevent any significant loading of the reference voltage dividers composed of R15 thru R18 and R19 thru R22. The voltage followers require very little input current and are able to provide large amounts of output current, although this latter capability is not significant in this case. In operation, IC9 and IC10 will act as necessary to balance their inputs, Pins 2 and 3. From inspection of the circuit, since the output (Pin 6) is connected directly to the inverting input (Pin 2), it is obvious that the output of these circuits will always be the same as their input, which is 0v to 1.666 volts, and is applied to Pin 3. The gain of these circuits is therefore equal to 1.0, and for this reason they are sometimes called non-inverting unity gain buffer circuits. C6 and C7 are the compensation capacitors for these buffers.

Trimming potentiometers R16 and R20 are used to set the outputs of IC9 and IC10 at exactly -1.666v and +1.666v, respectively, when R18 and R22 have been set to "1000" (or fully clockwise).

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

Transistors Q1 and Q2 are the upscale and downscale choppers. These are field effect transistors, or "N-channel JFET's". Their gate, source and drain terminals are identified on the schematic diagram. The voltage which is applied to the gate terminal of the JFET is used to control the resistance between its source and drain terminals. When the gate terminal is more negative than -1.8 volts, with respect to the source terminal, the resistance between the source and drain is essentially infinite. Conversely, when the gate-source voltage difference is zero, the source-drain resistance is less than 1000 ohms.

From the previous explanation of the gate circuits IC7 and IC8, recall that the output of IC7 will be -14 volts, except when the output set point signal is lower than the input set point signal, in which case a series of pulses will be sent to CR3. These pulses will have a PW of 0.5, 5.0 or 50mS, a PRF of 2 PPS and will achieve a peak amplitude of +14 volts. They ride a -14 volt reference.

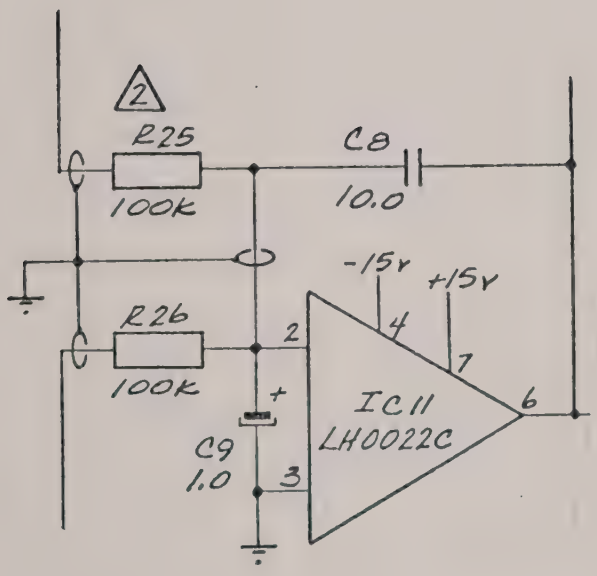
When the input to CR3 is -14 volts, either between pulses or in the absence of pulses from IC7, CR3 will be forward biased. Current will flow from IC7-6, thru CR3, thru R23 and into IC9-6. Pin 6 of IC9 can never be more negative than -1.666 volts, which assures that CR3 will always be forward biased when IC7-6 is at -14 volts. The maximum voltage drop at CR3 is about 0.7 volt. Hence, the gate of Q1 will be at a potential of about -13.3 volts during this condition, and the source-drain resistance will be essentially infinite (greater than 15,000 Megohms).

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

When the Slope Generator is in an "upscale" mode, the positive pulse train will be presented to CR3. Since these pulses may achieve an amplitude of +14 volts, each such pulse will reverse bias CR3, and no current will flow through the diode for the duration of the pulse. During this time, the gate voltage of Q1 will be the same as its source voltage, since it is connected to Pin 6 of IC9 through R23, and since there is no current thru, and so no voltage drop across, R23. Since the gate-source voltage difference at the JFET is zero, its source-drain resistance will be less than 1000 ohms. This low resistance then permits the output of IC9, the 0v to -1.666v reference voltage to be felt at R25. After the positive pulse has passed, the gate will once again be at the -13.3 volt potential and the JFET will revert to its blocking state.

To summarize, the JFET Q1 acts like a switch which is controlled by the precision timing pulses, which are gated through IC7 whenever the Slope Generator is in an upscale mode. This chopper, or "switch", connects the negative reference voltage provided from IC7-6, to R25 during its short ON intervals. The result is that the input to R25, during the upscale mode, will be a series of pulses having a PRF of 2pps, a PW of 0.5, 5.0 or 50mS (depending upon S1) and whose amplitude is set by the "Slope Rate" adjustment R18 over the range of 0v to -1.666 volts.


2
R25
100K
C8
10.0
-15V
+15V
R26
100K
2
4
7
+
IC11
LH0022C
6
C9
1.0
3

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

The operation of the downscale chopper, Q2, is the same as that of Q1, except that it operates only while the Slope Generator is in the downscale mode, and passes pulses having an amplitude of 0v to +1.666v, as set by the downscale "Slope Rate" adjustment R22. A detailed evaluation of this circuit is left as an exercise for the reader.

(Diagram)

IC11 and its associated components form the slope generating circuit. It can be seen by casual inspection that, except for component values, this circuit is essentially the same as the "mesa" wave generator circuit, IC2.

The input to the slope generator circuit is derived from either Q1 or Q2. Note that this is an "either, or" situation; inputs are never provided simultaneously from both of these sources. Furthermore, at times when the output set point signal is equal to the input set point signal, there will be no input to IC11 from either source.

So far as the two possible inputs are concerned, it is important to realize that they will always be identical, except in terms of amplitude and polarity. Recapping: the input, when present, is always a pulse train whose PRF is 2 pps, and whose PW is:

S1 Position	PW
X.1	0.5ms
X1	5.0ms
X10	50ms

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

If the input pulses are provided from the upscale chopper, Q1, their polarity is negative. Conversely, input pulses supplied by Q2, the downscale chopper, are of positive polarity. Finally, the amplitude of the pulses will be within the range of 0v to 1.666 volts, with the upscale and downscale systems being independently variable by means of the separate "slope rate" adjustments, R18 and R22.

In analyzing this circuit, the following case will be used:

Input Source: Q1 (upscale chopper)

Pulse Amplitude: -1.666 volts

Pulse Width: 0.5ms

This input is applied to R25. During the 0.5ms on time of Q1, IC11 produces a current of 16.66 uA thru R25 into one side of C8, and from the opposite side of C8 to its output, Pin 6. By virtue of this current, the voltage drop across R25 will be (E=IR) 1.666 volts. This leaves Pin 2 of IC11 at 0 volts (virtual ground) and thereby satisfied its "balanced inputs" requirement.

During this same interval, C8 is experiencing a constant current, 16.66 uA. From our evaluation of the IC2 circuit, recall that when subject to a constant current, a capacitor charges at a linear rate:

$$\Delta E_c = \frac{I}{C}$$

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

For this case, then, C8 charges at a rate of (16.66uA - 10ufd =) 16.66v/sec. However, each input pulse lasts for only 0.0005 second, so ΔE_c for each pulse is only 0.833 mv.

Since two pulses occur per second, ΔE_c is 1.666 mv/sec. Since one minute includes 60 seconds, ΔE_c is 100mv/min. (error due to rounding).

Since the direction of the current involved at C8 is towards Pin 6 of IC11, the charge across the capacitor, as measured between Pin 6 and ground (or the virtual ground, Pin 2), will grow increasingly more pisitive. Since the voltage at Pin 6 of IC11 is the unbuffered output set point signal, it is evident that this signal is being driven upscale towards its maximum +5 volt (100%) potential.

When the upscale chopper, Q1, switches to its OFF state, which lasts for 499.5ms between consecutive input pulses, the "input" tc R25 is zero. Since this, in itself, satisfies the "balanced inputs" requirement which IC11 acts to maintain at all times, there will be no current flow through R25, C8 or the output of IC11, Pin 6. Since $\Delta E_c = I \div C$, and since I = zero, it is evident that ΔE_c = zero. This means that the charge on C8 and, therefore, the output voltage at Pin 6 of IC11, do not change this interval. The output signal will, therefore, rest at whatever value it had achieved by the end of the last, most previous, input pulse.

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

The downscale input is provided through the downscale chopper, Q2, and is applied to R26. Operation in the downscale mode is just the same as in the upscale mode, except that the polarity of the downscale input pulses is positive. This means that the direction of the current which flows in the R26, C8, Pin 6 circuit is reversed, and flows from Pin 6, thru C8 and R26, to Q2. This means that the capacitor charges in the opposite direction (or discharges) and, hence, the output set point signal will be driven downscale towards its minimum 0volt (0%) level.

When the input pulses have an amplitude of 1.666 volts and a pulse width of 0.5ms, these parameters result from a "slope rate" setting of "1000" (or fully clockwise) and a multiplier switch (S1) setting of x.1mv/min. Hence, the Slope generator had been set to produce a transition rate of (1000 x.1mv/min) 100mv/minute, and, as was demonstrated above, this was achieved. By switching the scale multiplier switch, S1, to the X1 or X10 position, the output transiton rate would be changed to 1000mv/min, or 10,000mv/min, respectively. This follows, since in the X1 position, the pulse width becomes 5.0ms, and in the X10 position, 50ms (10 or 100 times longer, respectively).

As was seen above, the Slope Generator's output signal is incremented and decremented in a series of small steps. For the above case, the output changed ±833uV per step. Hence, the output signal takes the form of a "staircase" wave, ascending or descending.

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

It is important to emphasize three points. First, IC11 always does whatever is necessary to hold Pin 2 at the same potential as Pin 3 (i.e., ground potential). Second, both inputs are never ON at the same time. Third, the resistance from Pin 2 to the source terminal of an OFF chopper is so high (over 15,000 meg ohms), that for all practical purposes an "open circuit" exists along that path.

Naturally, the components used in the Slope Generator circuit are not perfect, although they approximate "ideals". The chopper JFETs manifest a small amount of drain-source leakage in the OFF state. Likewise, capacitor C8 is subject to a small amount of leakage. IC11's inputs also pass a small amount of current. As indicated in the specifications, the combined effect of these imperfections, when added to the possible errors affecting the PRF, PW and amplitude of the input pulses, might produce transition rate errors of "±1% ROC plus ±5mv/min" at the worst, but typically within "±7% ROC plus ±.075mv/min". In other words, it should be possible to bring the transition rate accuracy within these limits, using the calibration procedures provided in this manual. When this is not possible, a defect in the circuit is indicated.

When a defect is suspected, first check the input pulses for PRF, PW and amplitude by connecting an oscilloscope to the drain terminals of Q1 and Q2. An OFF condition drain voltage of more than ±5uv indicates excessive FET leakage. Trace any other input discrepancy back towards the circuitry which is responsible for

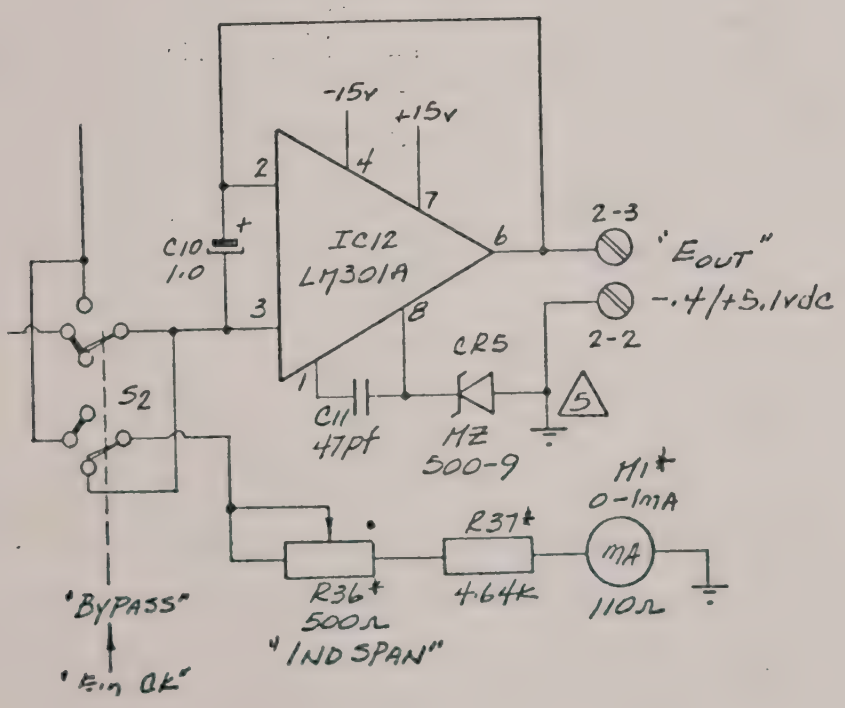
Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

the parameter in question. If the inputs are correct, slew the output to +5volts, then turn both slope rate adjustments (R18 and R22) fully counterclockwise. All test equipment must be disconnected from the circuitry at this time. If the output gradually diminishes, probabilities favor capacitor leakage (C8). However, this could also indicate excessive input bias current at Pin 2 of IC11. To establish which, short Pin 2 to ground; if the drift persists, the cause is C8. If the drift diminishes significantly, or if the output drifted upscale prior to grounding Pin 2, IC11 is probably at fault.

In general, any measurements made at Pin 2 of IC11 will provide ambiguous and unreliable indications, since this part of the circuitry is quite vulnerable. Also, contamination of this area of the printed circuit board can produce indications which appear to be faulty components, due to leakage currents across the board. If the board is not clean, clean it with chlorthene or a freon cleaning agent, being careful to remove any and all films and residues prior to any further troubleshooting.

Finally, capacitor C9 is used to prevent the input FET's within IC11 from being forward biased by transient noise signals. This capacitor, effectively, shunts such signals to ground. In the absence of C9, noise signals can cause the output of IC11 to "step" erratically to values which are grossly in error (usually in the downscale direction).


-15v
+15v
4
2
7
IC12
LM301A
6
3
8
1
C10
1.0
C11
47pf
CR5
MZ
500-9
2-3
"EOUT"
-.4/+5.1vdc
2-2
5
S2
"BYPASS"
"Ein OK"
R36*
500Ω
"IND SPAN"
R37*
4.64k
M1*
0-1mA
mA
110Ω

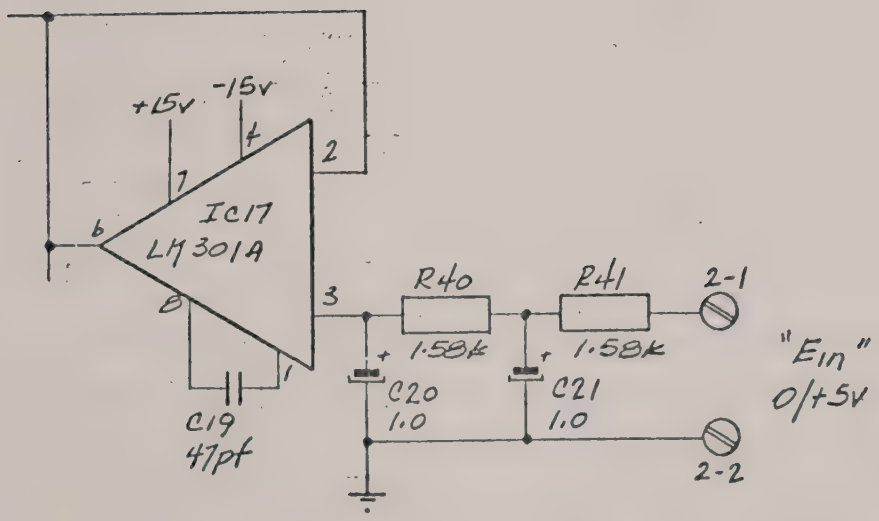
Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

IC12 is the output buffer circuit. This circuit isolates the Slope Generator circuitry from the possible effects of output loading. Upon inspection, it can be seen that, except for minor variation, IC12 is simply a non-inverting unity gain voltage follower, similar to IC9 and IC10. In this case, however, the output is limited to the range of -0.7v to +5.1v by zener clamping diode, CR5. C11 is the compensation capacitor for IC12. C10 serves to commonize the inputs of IC12 for ac noise signals. This permits the common mode rejection of the op amp to cancel these signals so that they will not appear in the output.

(Diagram IC12)

Meter M1 and its series resistors R36 and R37 are provided as a part of the Slope Generator Indicator/Control Station. A current of 1ma produces full scale deflection of the meter's indicating pointer. A current of 1ma will result when a +5volt signal is applied to R36, and when R36 is adjusted to provide a total series resistance of 5kΩ. The meter scale is typically calibrated -125°F to +375°F, with an equivalent °C scale, according to the response curve of a copper vs. constantan (Type T) thermocouple temperature sensor. As a result, it indicates temperature settings directly. The scale of the meter can, however, be calibrated to accommodate any curve and any system of engineering units.


+15v
-15v
IC17
LM301A
R40
R41
2-1
1.58k
1.58k
"Ein"
0/+5v
C20
1.0
C21
1.0
C19
47pf
2-2

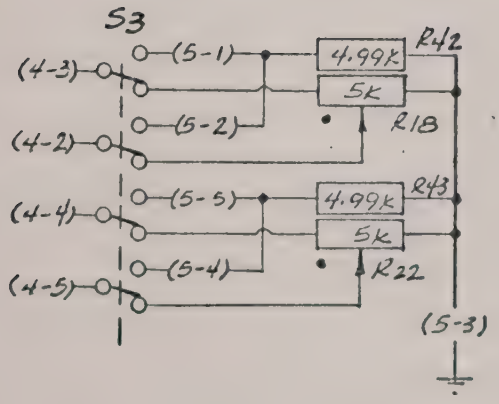
Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

Switch S2 provides a means of monitoring either the input signal or the output signal on Meter M1, and also a means of connecting the input setpoint signal directly to the output, thereby "bypassing" the Slope Generator. As can be seen, the Slope Generator provides its normal output when this switch is in either the "NORM" or "EinCK" position. In the "NORM" position, the meter indicates the value of the output signal, while in the "EinCK" position, the meter is connected to the input signal. In the "bypass" position, the input signal is connected directly to the output, and the meter reading is applicable to both the input and output.

IC17 Diagram

IC17 buffers the set point input signal, and is idential to IC12, except that this circuit is not clamped. In this case, a two section L-type filter is used to attenuate noise at the input terminals. Since the "reactance" of C20 or C21 is 159Ω for signals having a frequency of 1k Hz, each section of this filter acts like a voltage divider composed of a 159Ω element and a 1580Ω element. A noise signal at the input having a frequency of 10k Hz and an amplitude of 10 volts pk/pk, will appear at the R40, C21, R41 junction with its amplitude reduced by a factor of 100, to about 1mv pk/pk. As the noise frequency increases, the attenuation factor increases, and visa versa. For dc input voltages, the filter offers no attenuation, thereby preserving the accuracy of the input.


S3
(4-3)
(4-2)
(4-4)
(4-5)
(5-1)
(5-2)
(5-5)
(5-4)
4.99k
5k
4.99k
5k
R42
R18
R43
R22
(5-3)

Functional Analysis (Continued)

Pulse Forming Circuits (Continued)

(S3 Diagram)

The Indicator/Control Station also includes a third switch, S3, which allows remote programming of the slope rates. When this switch is in the "manual" position, R18 and R22 are connected in the circuit as shown on the Slope Generator schematic diagram. When this switch is in the "remote" position, remote programmable potentiometers are connected to IC9 and IC10 in place of R18 and R22. These remote potentiometers are connected to the terminal block on the back of the Indicator/Control Station.

It is permissible to provide remote program slope rate signals, 0v to ±1.666 volts, instead of remote program potentiometers.

Where this programming capability is not used, S3 can be used to provide one of two other functions. The switch can be wired so that in the "remote" position, it connects Pin 3 of IC9 and IC10 either to ground, or to the wipers of R16 and R20. The "remote" position provides the maximum ROC obtainable for the multiplier setting of S2. These options are achieved by connecting jumper wires at the terminal block on the back of the Indicator/Control Station. As delivered from the factory, the unit is normally wired to provide the fast ROC when S3 is switched to "remote".

Alignment and Calibration

The Slope Generator can be calibrated quickly and easily when the following test equipment is available:

- a stop watch
- an oscilloscope with an accurately calibrated time base
- a digital voltmeter capable of reading 2 volts to two decimal places.

These are the minimum requirements. If a frequency counter is available, it may be used to measure frequency and pulse width, and further simplify the effort. A common analog VOM should never be used in place of the DVM.

(1) Remove the cover from the Slope Generator by depressing its ends to release the catches.

(2) All input and output connections should be in their normal configuration for the system in question.

(3) Set the controls on the Indicator/Control Station as follows:

S1 :X.1mv

S2 :"NORM"

S3 :"MANUAL"

U/S Rate :"999" + 1 (1000)

D/S Rate :"999" + 1 (1000)

(4) If the system does not include an Indicator/Control Station, turn R18 and R22 fully clockwise, then inspect TB3 and TB4 to ascertain whether the unit has been wired for "X.1mv", "X1mv", or"X10mv" operation

(4) Continued.

Jumpered Terminals	Rate Range
TB3 - 1 to TB4 - 6	X0.1 mv
TB3 - 1 to TB4 - 7	X1.0 mv
TB3 - 1 to TB4 - 8	X10 mv

Note this connection, then rewire the unit for "X0.1mv" operation as above.

CAUTION

The Slope Generator circuit board assembly carries potentials of 115vac near TB1 and the power supply circuitry. Take care to AVOID these areas and the attendant DANGER OF SEVERE ELECTRICAL SHOCK.

WARNING

In control applications, the Slope Generator output is used to provide control voltage signals to REMOTE EQUIPMENT. Prior to proceeding, take steps to assure that any such equipment is POSITIVELY DISABLED, so that the random output produced during calibration will not cause such equipment to be operated in potentially dangerous modes.

(5) Apply power to the Slope Generator at TB1:

L = Line)
N = Neutral) 115vac 50/60 Hz
E = Earth)

Alignment and Calibration (Continued)

(6) Connect the DVM to the +15vdc power supply:

(+) lead to TP-1

(-) lead to TP-G

(7) Adjust R31 to provide a DVM indication of exactly +15.000 volts.

(8) Connect the DVM to the -15vdc power supply:

(+) lead to TP-2

(-) lead to TP-G

(9) Adjust R33 to provide a DVM indication of exactly -15.000 volts.

(10) Disconnect the DVM.

(11) Connect the oscilloscope to the 1 Hz clock circuit:

(+) lead to TP-3

(-) lead to TP-G

(Set the sweep rate to about 1 sec/cm and the vertical gain to about 5v/cm. Internal trigger.)

(12) The scope should display a square wave signal having a frequency of about 1.0 Hz and an amplitude of ±14vdc. If the calibration of the scope is reliable, set R3 as required to produce a frequency of exactly 1.0 Hz (one cycle per second). If the accuracy of the scope on this slow range is questionable, count cycles during a two minute interval using the stop watch to verify the frequency setting:

$$F = \frac{\text{cycles counted}}{120}$$

(13) Connect the scope to the output of the pulse forming circuits:

(+) lead to TP-4

(-) lead to TP-G

(Set the sweep rate to about 100 uS/cm and the vertical gain to about 5v/cm. Internal trigger.)

Alignment and Calibration (Continued)

(14) The scope should display a pulse having a recurrance rate of 2pps, an amplitude of ±7vdc, and a pulse width of 0.5ms. Adjust R11 to produce a pulse width of exactly 0.5ms.

(15) Switch S1 to the "X1mv" position.(For wired applications see Step 4 and reconnect the jumper wire.) The pulse width, as displayed on the scope should now be about 5.0ms. Adjust R9 to produce a pulse width of exactly 5.0ms (sweep rate set to 1ms/cm).

(16) Switch S1 to the "X10mv" position. (For wired applications see Step 4 and reconnect the jumper wire.) The pulse width as displayed on the scope, should now be about 50ms. Adjust R7 to produce a pulse width of exactly 50ms (sweep rate set to 10ms/cm).

(17) Disconnect the scope. Set S1 (or rewire) for "X.1mv".

(18) Connect the DVM to the negative precision reference voltage circuit:

(+) lead to TP-5

(-) lead to TP-G

(19) Adjust R16 to provide a DVM indication of exactly -1.666 volts.

(20) Connect the DVM to the positive precision reference voltage circuit:

(+) lead to TP-6

(-) lead to TP-G

(21) Adjust R20 to provide a DVM indication of exactly +1.666 volts.

(22) Set the input to the Slope Generator at its 0% value. Connect the DVM to the output terminals:

(+) lead to TB2 - 3

(-) lead to TB2 - 2

(23) The DVM indication should be between zero volts and +5 volts, and should be diminishing at a rate of about 100mv/minute. Verify this rate by measuing the time required for the output to diminish from one point to another, using the stopwatch and the DVM indication. The measuring interval should be at least two minutes. Compute the actual transition rate as follows, and record the result:

$$\text{Actual ROC} = \frac{E1 - E2}{\Delta t}$$

where:

E1 = Output voltage at t_o (volts)

E2 = Output voltage at the end of the timing interval (volts)

Δt = Length of timing interval (minutes)

ROC = Volts per minute

(24) Now check the upscale transition rate by setting the input at +5 volts, and timing a transition as per Step 23 above. Record the calculated transition rate.

(25) Inspect the results of Steps 23 and 24.

a. If <u>both</u> the upscale and downscale transition rates are too fast or too slow, the adjustment of R11 must be corrected. Compute the correction factor as follows:

$$\text{factor} = \frac{\pm \text{ROC (mv/min)}}{100}$$

Now reconnect the scope to TP-4 and measure the pulse width. Multiply the measured pulse width times the

(25) Continued:

a. correction factor and re-adjust R11 to produce this new pulse width.

b. If the upscale and downscale transition rates are not equal, but both too high or too low, correct the smaller error, using the above procedure. Then correct the upscale - downscale difference using the following procedure.

c. If only one of the transition rates is incorrect, or to correct the error which remains in one direction after having recalibrated PW to correct for the smaller error in the opposite direction, calculate a correction factor as follows:

$$\text{factor} = \frac{\text{ROC(mv/min)}^*}{100}$$

*If the pulse width has been recalibrated, multiply the ROC which includes the larger error by the correction factor previously calculated in Step 25a, and use the result in the above formula.

If correcting the upscale ROC, connect the DVM to TP-5. If correcting the downscale ROC, connect the DVM to TP-6. Multiply the DVM indication (approx. ±1.666v) by the correction factor computed immediately above. Readjust either R16 (D/S cal) or R20 (U/S cal) to produce the indication calculated here.

(26) If desired, the transition rates may now be rechecked by repeating Steps 23 and 24.

(27) If it was necessary to recalibrate the "X0.1mv" range, it is likely that the "X1.0mv" and "X10mv" ranges would have proven to be inaccurate by about the same factor. Since the adjustment of R11, R18 and R22 affects the calibration of all three ranges, all three should now be correct. If desired, however, the "X1,0mv" and "X10mv" may be tested and, if necessary, recalibrated by means of R9 and R7, respectively. If calibrating these ranges, the divisor used in the formula given in Step 25a will be 1000 and 10,000, respectively. Only the pulse width may be recalibrated on these ranges; R11, R16 and R20 must not be moved. If measurements indicate a u/s vs. d/s differential rate error, this indicates that the "X0.1mv" scale was recalibrated incorrectly, and that procedure should be carefully repeated.

(28) If the system includes an Indicator/Control Station, set S1 to "bypass" and connect the DVM to the output:

(+) lead to TB2 - 3

(-) lead to TB2 - 2

Set the output to exactly zero volts. (Be sure to zero the DVM.) Then adjust the mechanical zero adjustment on the face of the meter as necessary to set its indicating pointer exactly over the left-end scale mark (0%). Then set the output to exactly +5.000 volts and adjust R36, on the back of the Indicator/Control Station as necessary to set the indicating pointer exactly over the right-end scale mark (100%).

(29) This completes the calibration procedure. For units which do not include an Indicator/Control Station, refer back to Step 4 and reconnect the jumper wire as per its original connection. Disconnect all test equipment and remove power from the Slope Generator prior to replacing its cover. If remote equipment was disabled during the calibration procedure, be certain to restore it to operable condition.

ALTERNATE PROCEDURES

Unless a good laboratory oscilloscope is available, it might be difficult to achieve accurate measurements of pulse width.

If a frequency counter is available, its use can greatly simplify frequency and pulse duration measurements, and better accuracy should result.

In the absence of either a good scope or a frequency counter, an accurate DVM may be used to measure the pulse widths. In this case, connect the DVM:

(+) lead to TP-4A

(-) Lead to TP-G

The voltage at this point is related to the pulse width by a factor of 0.1v/ms:

S1 Position	PW	TP-4A
X10	50ms	5.00v
X1	5ms	.500v
X.1	.5ms	.050v

Use these voltage measurements in place of the pulse width measurements in Steps (13) through (16), and in Step (25).

MAINTENANCE

The SlopeGenerator requires no periodic maintenance, as such. Good maintenance practice suggests that the unit be inspected from time to time for contamination, loose connections, etc. The practical inspection interval will vary with the application and the nature of the environment in which the unit is used.

If necessary, blow accumulations of dust out of the unit using compressed air (30psi max.). In extreme cases all parts of the unit except the meter may be cleaned of accumulated dirt using a chlorthene or freon solvent followed by a thorough rinse with demineralized water. Insure that the unit is thoroughly dried out prior to reassembly and return to service.

The desired calibration interval must also be established by the user. In this type of equipment component aging is usually responsible for calibration drift. In the case of the Productsaver however, the use of top quality solid state and passive components minimizes the probability of such variation, and should be considered when establishing calibration varification requirements.

When the equipment was designed, the importance of reliability in this type of instrumentation was recognized. For this reason the circuit includes a high level of redundancy. Only top quality component parts are used in its construction, and each part is conservatively rated. If and when failures do occur, troubleshooting is simplified by the fact that most of the individual circuits within the unit consist of an integrated device. These devices typically combine forty to seventy circuit elements into a single replaceable package, leaving only a few discrete components on the outside. Furthermore, each section of the circuit usually performs a single, clearly identified function, and it is therefore fairly simple to work thru the entire circuit on a GO/NO–GO basis until the faulty circuit is isolated.

When troubleshooting becomes necessary, there is simply no substitute for knowledge. With this in mind, a comprehensive explanation of the circuit is provided in this manual under the heading FUNCTIONAL ANALYSIS. This explanation includes the designed purpose of every electronic component part. Sometimes a visual inspection of the circuitry will locate the fault in short order. Where this is not the case, poking around in unfamiliar circuitry and replacing suspect parts usually wastes a lot of time and a lot of parts. In such cases, it is usually much more expedient to simply sit down for an hour or two and study the circuitry until it is reasonably well understood, prior to doing any actual troubleshooting.

When troubleshooting any electronic circuit, its dc power supplies must always be tested for proper operation as THE FIRST STEP. the output of these supplies should be within 1% of their assigned values, except for the 30vdc unregulated supply, which may vary by ±15%. Other than this, and because of our philosophy, as expressed above, Thermotron has provided no 'troubleshooting guide' as such, in this manual.

SERVICE

Where troubleshooting assistance is required, phone or write Thermotron - ACS Customer Service (see back cover).

Users desiring to return units for service at the factory should contact Thermotron - ACS Customer Service in advance for a returned goods authorization number. Returned units shoud be CAREFULLY PACKED TO PREVENT DAMAGE IN SHIPMENT. Double packing (two cartons, each with excelsior all around the contents) is recommended.

All returns should be accompanied by a purchase order showing the Thermotron returned goods authorization number, return shipment instructions, the nature of the service requirement (what seems to be wrong, with as much detail as possible), and the name of a person at the customer's plant who can be contacted for further information.

All shipping related to service is handled FOB Holland, Michigan. UNITS ARRIVING AT HOLLAND IN AN APPARENTLY DAMAGED CONDITION OR WITHOUT PRIOR AUTHORIZATION CAN NOT BE RECEIVED. All units accepted for service will receive immediate attention at the factory, with 24-hour turn-arounds provided in many cases. Unless otherwise specified on your order, outbound repaired units will be shipped using the same method as the inbound shipment.

Orders for service parts should also be directed to Thermotron - ACS Customer Service. All parts are normally stocked at the factory, and in most cases 'same-day' shipment can be provided. In order to expedite service and assure that the correct parts are shipped, all items should be identified by the Thermotron six-digit part number (IISS number), in addition to their noun and spec.

e.g.

052347 RESISTOR, Film 2.4K ¼w 1%

- Photo Req'd -

PARTS LIST

Slope Generator Assy.
013008

IISS	Description	Qty
048030(1)	PCB ASSY., Slope Gen	1
251005	GROMET, 3/16 x 5/16 x 1/16	2
251006	GROMET, 1/2 x 3/8 x 1/16	1
271005	SCREW, Bdr.Hd. 4-40 x 3/8	6
272003	WASHER, Flt #4	6
273002	LOCKWASHER, Int #4	6
279005(2)	THREADSPACER, 4-40 x 1/4	6
351011(2)	CHASSIS, S.G.	1
353008	COVER, S.G.	1
451008	USER'S MANUAL	1

(1) Illustrated parts breakdown provided for these items.

(2) Not independantly replacable. Order both 279005 (6) and 351011 (1).

- Photo Req'd -

PARTS LIST

PCB Assy., Slope Generator

048030

IISS	Description	Qty
051784	RESISTOR, W.W. 3.0Ω 2w 5%	1
051785	RESISTOR, 5.1Ω	1
052205	RESISTOR, Film 110Ω 1/4w 1%	1
052234	RESISTOR, 221Ω	3
052249	RESISTOR, 316Ω	2
052321	RESISTOR, 1.58k	2
052338	RESISTOR, 2.43k	2
052341	RESISTOR, 2.61k	2
052390	RESISTOR, 8.45k	1
052401	RESISTOR, 10k	2
052411	RESISTOR, 12.7k	1
052466	RESISTOR, 47.5k	1
052501	RESISTOR, 100k	6
052515	RESISTOR, 140k	1
052508	RESISTOR 118k	1
052513	RESISTOR, 133k	1
052568	RESISTOR, 499k	1
054001	POTENTIOMETER, Trim 100Ω 25T	4
054003	POTENTIOMETER, 2k	2
054004(1)	POTENTIOMETER, 5k	1
054010	POTENTIOMETER, 25k	1
062001	CAPACITOR, Disc. 47pf 1kv	8
062004	CAPACITOR, .01uf 100v	2
063002	CAPACITOR, Tant. 1.0uf 50v	5
063003	CAPACITOR, 4.7uf	1
064002	CAPACITOR, Elec. 250uf 50v	2
067001(2)	CAPACITOR, Poly. 1.0uf 50v	2
067002(2)	CAPACITOR, 10uf 50v	1

PARTS LIST (Continued)

PCB Assy., Slope Generator

048030

IISS	Description	Qty
071001	TRANSFORMER, Pwr, 115v/40vct	1
081007	DIODE, Rect. 1N4002	6
081008	DIODE, Zen. MZ500-9	3
081011(3)	DIODE, MZ500-17	2
083003	TRANSISTOR, Pwr 2N4898	2
083006(2)	TRANSISTOR, FET 2N4339	2
093001	I.C., Op Amp LM301AH	14
093003	I.C., Pos Reg LM305AH	1
093004	I.C., Neg Reg LM304H	1
093007(2)	I.C., Op Amp LH0022CH	1
176002	TERMINAL BLOCK, 3-w SEPCR	1
176003	TERMINAL BLOCK, 3-w EPCR	1
176008	TERMINAL BLOCK, 8-w SEPCR	2
179001	SOLID PIN, PCB	9
201037	PTD. CKT. BOARD	1
233006	HEAT SINK, TO-66 Flt	2
271005	SCREW, Bdr.Hd. 4-40 x 3/8	4
273007	LOCKWASHER, Int. #4	4
274002	NUT, Hex #4	4

(1) Qty reqd is 3 if 013009, or equiv., is not provided.

(2) Failure to use exact replacements may radically degrade performance and produce unsafe operating modes.

(3) CR5 is selected for V2 of 5.1 to 5.5vdc.

(PHOTO REQ'D)

PARTS LIST
Slope Gen. Indicator/Control Station
013009

IISS	Description	Qty
052368	RESISTOR, Film 4.64k 1/4w 1%	1
052368(1)	RESISTOR, 4.99k	2
054011	POTENTIOMETER, Dial 5k	2
054012	POTENTIOMETER, Trim 500Ω 1T	1
081012	DIODE, LED OSL-3	2
101001	SWITCH, Toggle 2P3T	2
101006	SWITCH, 4P2T	1
123004(2)	METER, Temp. -125/+375°F T	1
176012	TERMINAL BLOCK, 5-w SEIFC	1
194004	CABLE CONTROL, 20-c x 4 ft.	1
198003	CABLE TIE, 0 - .75	2
198005	SHRINK TUBE 3/32 x .500lg. wht	48
251006	GROMET, 1/2 x 3/8 x 1/16	1
254001	HOLDER, LED	2
271065	SCREW, Fl.Hd. 4-40 x 3/8	2
272003	WASHER, Flt. #4	2
272004	WASHER #6	4
273002	LOCKWASHER, Spt. #4	2
273003	LOCKWASHER, Spt. #6	4
274002	NUT, Hex #4	2
274003	NUT, #6	4
351010(2)	PANEL CONTROL, S.G.I.C. (°F/min)	1
352004	CHASSIS, S.G.I.C.	1
353007	COVER, S.G.I.C.	1
451008(3)	USER'S MANUAL	-

(1) Not reqd. for programmed applications.
(2) Other ranges will have a different part number.
(3) Provided with Slope Generator 013008.

PARTS LIST, Symbolic

C1	067001
C2	067001
C3	062001
C4	062001
C5	062001
C6	062001
C7	062001
C8	067002
C9	063002
C10	063002
C11	062001
C12	062004
C13	062004
C14	064002
C15	064002
C16	063002
C17	063003
C18	062001
C19	062001
C20	063002
C21	063002
CR1	081011
CR2	081011
CR3	081007
CR4	081007
CR5(1)	081008
CR6	081008
CR7	081012
CR8	081008
CR9	081012
CR10	081007
CR11	081007
CR12	081007
CR13	081007
IC1	093001
IC2	093001
IC3	093001
IC4	093001
IC5	093001
IC6	093001
IC7	093001
IC8	093001
IC9	093001
IC10	093001
IC11	093007
IC12	093001
IC13	093001
IC14	093001
IC15	093003
IC16	093004
IC17	093001

M1	123004
Q1	083006
Q2	083006
Q3	083003
Q4	083003
R1	052568
R2	052508
R3	054010
R4	052513
R5	052515
R6	052534
R7	054001
R8	052338
R9	054004
R10	052466
R11	054001
R12	052205
R13	052401
R14	052401
R15	052341
R16	054001
R17	052249
R18	054011
R19	052341
R20	054001
R21	052249
R22	054011
R23	052501
R24	052501
R25	052501
R26	052501
R27	052234
R28	052234
R29	051784
R30	052411
R31	054002
R32	052390
R33	054003
R34	052338
R35	051785
R36	054012
R38	052501
R39	052501
R40	052321
R41	052321

S1	101001
S2	101001
S3	101006
TB1	176003
TB2	176002
TB3	176008
TB4	176008
TB5	176012
T1	071001

(1) Select CR5 for V2 = 5.1 to 5.5vdc.

ENGINEERING CHANGE NOTICE

To: File 459012

FROM: G. Warner

DATE: 24 April 1975

SUBJECT: Slope Generator Design Change Notice

REFERENCE: Model 013008/009

The purpose of this design change is to establish a fixed operating mode for the flashing indicator lights on this equipment. In the original design the mode of operation at the balance point was not controlled, with the result that either both lights flashed, or both lights remained off. This matter was discussed in detail in Application Note 453013.

Although the indeterminate indicator mode in no way effects the performance of the equipment, it has become a point of contention between two factions . . . those who feel that it is a superficial concern, and those who feel that it creates a 'human factors' problem in practical use.

In order to promote greater harmony, and under the assumption that none would object to a fixed mode of operation for the indicators, the circuitry has been slightly modified towards that end.

This modification, shown on the attached diagram, will permit either mode to be established by means of the balance adjustments, R44 and R45. In production equipment, these adjustments will be set such that both indicator lights will be off at the balance point.

This modification will be applied on all units manufactured after this date. Applicable parts lists and technical information have been changed as required.

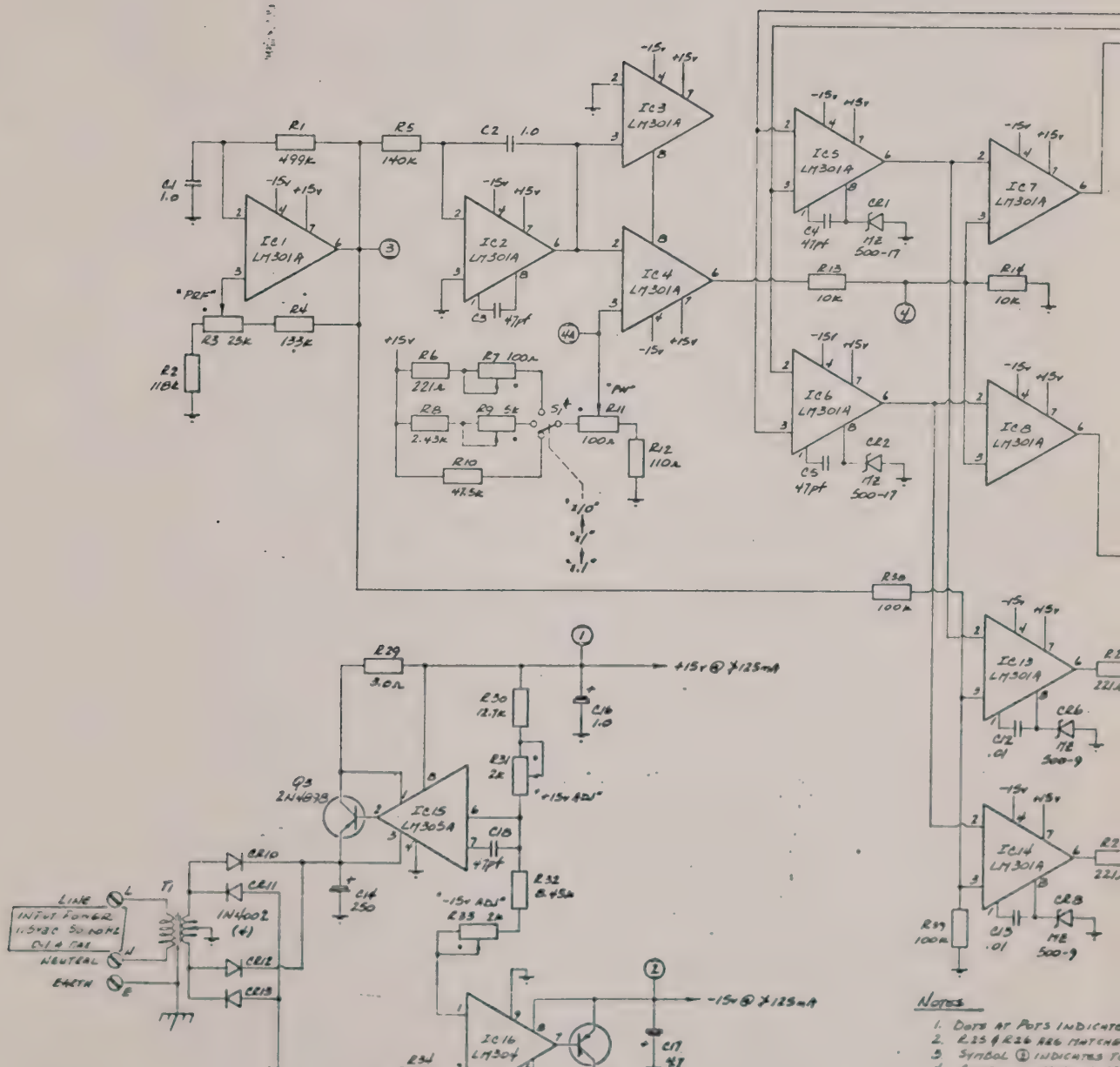
As noted in AN453013, the indeterminate indicator mode is the result of small input offsets at control circuits IC5 and IC6. These IC's have been changed from LM301A's to LM741C's because of the latters simplified offset balancing provision. The potentiometers R44 and R45 are then used to provide a means of balancing the offsets. Since the LM741C cannot be clampped as per the LM301A, the output clamp circuits R42/CR1 and R43/CR2 replace the previous connection of these diodes at pin 5 of the LM301A.

Parts Changes are Summarized As Follows:

ITEM	FROM	TO
C4	47 pf (pn062003)	None
C5	47 pf (pn062003)	None
IC5	LM301A(pn093001)	LM741C (pn093012)
IC6	LM301A	LM741C (pn093012)
R42	None	8.45K (pn052390)
R43	None	8.45K (pn052390)
R44	None	20K25tw (pn054009)
R45	None	20K25tw (pn054009)

THERMOTRON

SCHEMATIC DIAGRAM SLOPE GENERATOR INDICATOR CONTROL CIRCUITS		
C459012		
BARNE		470528

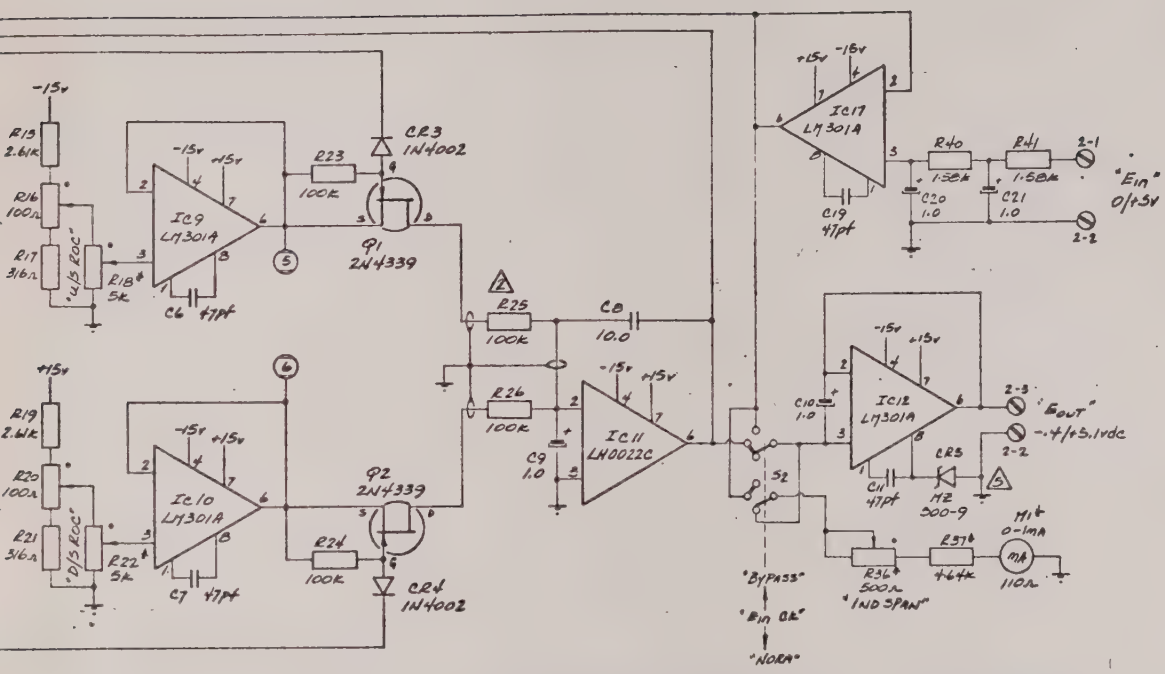


NOTES

1. DOTS AT POTS INDICATE
2. R33 & R34 ARE MATCHED
3. SYMBOL ① INDICATES T
4. COMPONENTS MARKED (*
R15 & R22 ARE TA
OPERATOR ADJ
CONNECTIONS WIL
INTERCONNECTIN

2 *CR5 MUST BE SELECTED

SYSTEM SCHEMATIC DIAGRAM
SLOPE GENERATOR (TM)
REF: 01300B & 01300A
470217



CALIBRATION & MINIMUM PERFORMANCE DATA			
TEST PT	OBSERVATION	TOL	ADJ
①	+15vdc	± 10mV	R31
②	-15vdc	± 10mV	R33
③	+4v, 0, -4v; 1.0Hz	E_{PK}: ±.5v; FREQ: ±.25%	(IC11) R3
④	PRF=2Hz; +7v, -7v; PW = 50% S1 POS.	PRF: ±.25%; E_{PK}: ±1v; PW: ±.5%	(R3) R11 R7 OR R9 AS APPL.
④A	+0.5v AS1 POSITION (ADJ. TO ④ ABOVE)	±.1%	R11 R7 OR R9 AS APPL
⑤	-1.667 vdc*	±1mv	R16
⑥	+1.667 vdc*	±1mv	R20

* RHEOSTS SET TO "999"+1 OR FULLY CLOCKWISE
** ALWAYS PERFORM TESTS IN THIS ORDER. REFER TO USER'S MANUAL #5106B FOR DETAILS.

WIRING INFORMATION	
TERM #	CKT
TB1-1	LINE
-2	NEUTRAL
-3	EARTH
TB2-1	Ein (+)
-2	Gnd
-3	Eout (+)
TB3-1	S1-R11
-2	S2-IC11
-3	IC17-S2
-4	R28-CR9
-5	R27-CR7
-6	n/c
-7	S2-IC12
-8	Gnd (*)
TB4-1	ISO Gnd
-2	R18-IC9
-3	R16-R18
-4	R20-R22
-5	R22-IC10
-6	R10-S1
-7	R9-S1
-8	R7-S1.

* Gnd connection for CR7 & CR9 only.

NO.	DATE	INIT.	REVISION
1	10/15	K.	5V CHGD TO 5.1V, SHIFTED 400mV, "ENGR" ADDITION
2	12/21	K.	INPUT BUFFER, IC17, ADDED
3	2/28	K.	470Ω RES. PACK, 33 DIODE, CR1 & R39, AND WIRING TABLE
4	4/28	K.	CORRECT TB3 CONNECTION DATA
5	11/87	GL	ADDED REAR PANEL CHANGES

(TM) RANGE MARK - THERMOTRON CORPORATION

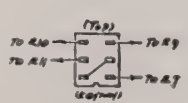
CR7 & OSL-3

CR9 & OSL-3

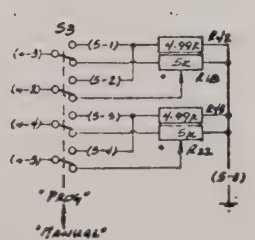
...AT CW POSITION OR WIPER.
...TO WITHIN ±.05% (HEAT SINK WHILE SOLDERING).
...POINT APPL. TO CALIB. PROCEDURE OR MIN. PERFORMANCE CHECK.
...RE MOUNTED REMOTE FROM PCB ASSY 04B030 IF USED.
...TED ON THE CIRCUIT BOARD IN CASES WHICH DO NOT REQUIRE ...TMENT CAPABILITIES. WHEN S1 AND/OR S2 ARE OMITTED, THESE ...B "SOFT WIRED" AS APPLICABLE TO THE APPLICATION. REFER TO ...IRING DIAGRAM FOR DETAILS.
...2 1/2 = 5.1v TO 5.5vdc.

(TOP VIEWS).

Q1/Q2 IC1 -IC3 IC16 CR7/9

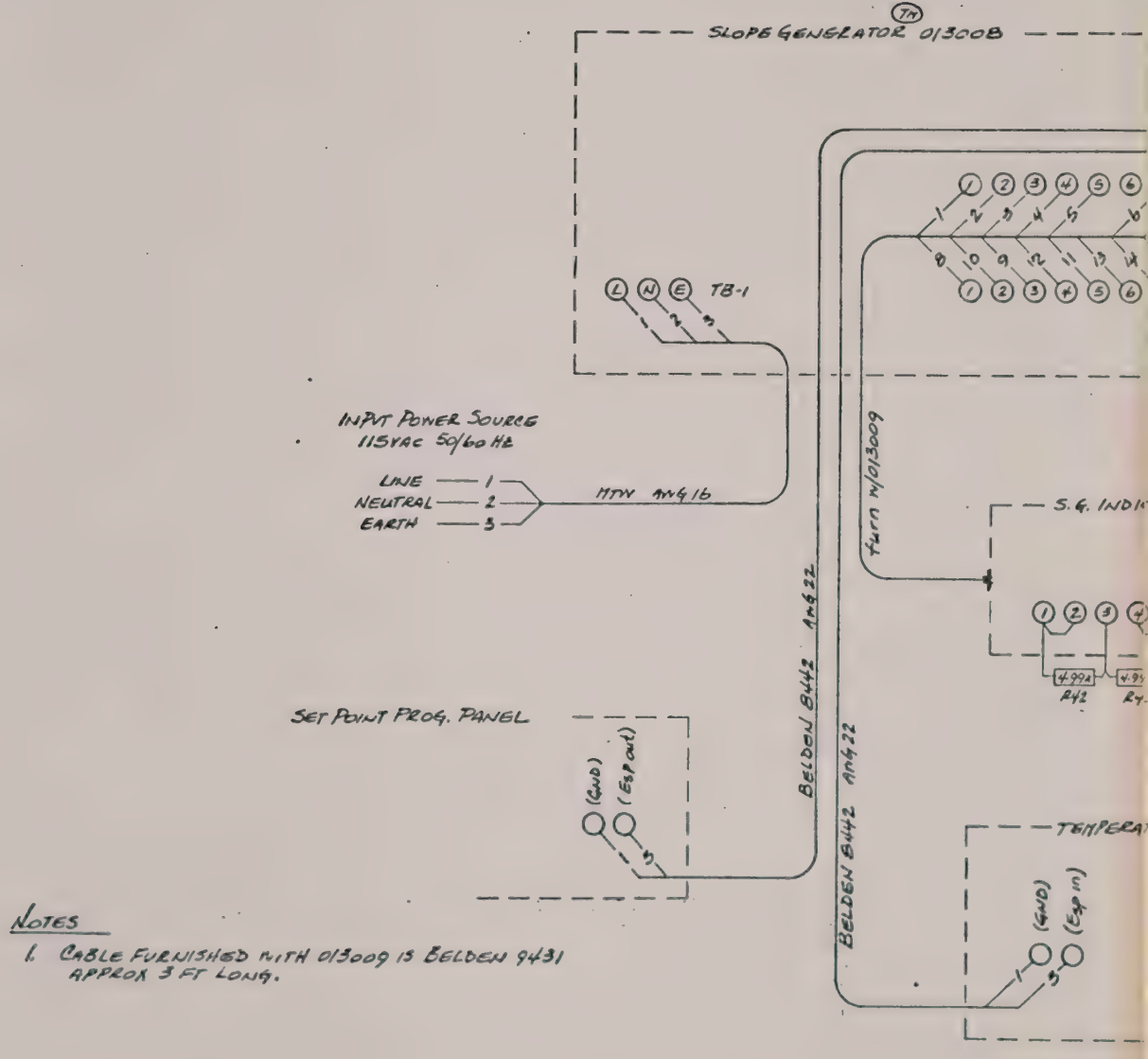


S1 WIRING INFO



STANDARD WIRING FOR S3. FOR DETAILS SEE DWGS 470224 & 470225

THERMOTRON
HOLLAND, MICH. USA

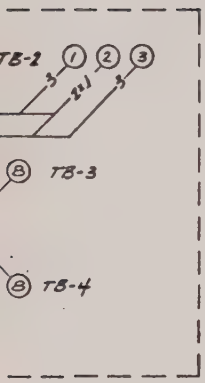


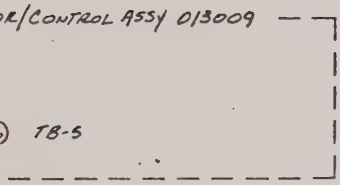
NOTES

1. CABLE FURNISHED WITH 013009 IS BELDEN 9431 APPROX 3 FT LONG.

THERMOTRON CORPORATION

HOLLAND, MICHIGAN 49423



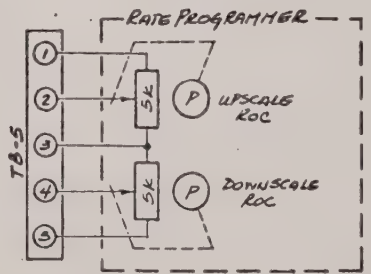


THESE TERMINALS FOR TRANSITION RATE PROGRAMMER. FOR PROGRAMMER WIRING SEE EXAMPLE BELOW. IN NON-PROGRAMMED SYSTEMS WIRE AS SHOWN TO TO PROVIDE RATE EQUAL TO "1000" DIAL SETTINGS WITH S3 IN "PROG" POSITION. FOR "STOP & HOLD" OPTION RECONNECT JUMPERS BETWEEN 2 & 3 and 3 & 4.

LE CONTROLLER

IPCEA COLOR CODE	
1	BLK
2	WHT
3	RED
4	GRN
5	ORG
6	BLU
7	WHT/BLK
8	RED/BLK
9	GRN/BLK
10	ORG/BLK
11	BLU/BLK
12	BLK/WHT
13	RED/WHT
14	GRN/WHT
15	BLU/WHT
16	BLK/RED
17	WHT/RED
18	ORG/RED
19	BLU/RED
20	RED/GRN

(INSULATED PWR CABLE ENG. ASSN)



TYPICAL RATE PROGRAMMER CONNECTIONS

CHANGES	DATE	BY	CHK'D

TOLERANCE

SCALE —

MATERIAL AS NOTED

FINISH —

DRAWN BY GRAINGER DATE 12 OCT 72

CHECKED BY DATE

RELEASED BY DATE

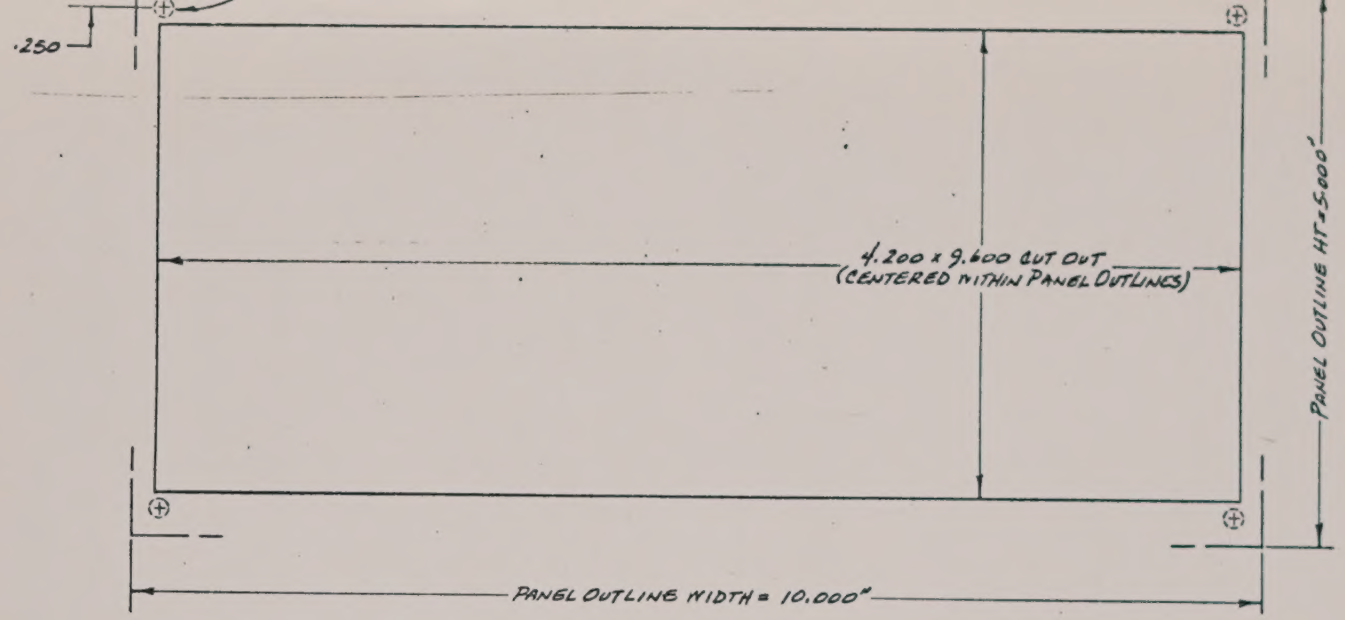
DESCRIPTION

TYPICAL WIRING INFORMATION FOR SLOPE GENERATOR™ SET POINT SYSTEMS

REF: 013008 & 013009

470224

™ TRADE MARK - THERMOTRON CORP, HOLLAND MICH 49417 USA 1972



MOUNTING INFORMATION FOR MODEL 013009
SLOPE GENERATOR™ INDICATOR/CONTROL STATION

NOTE: ZERO CLEARANCE REQD AT TOP AND BOTTOM, ONE INCH MIN CLEARANCE REQD ON BOTH SIDES. AFT SECTION PROTRUDES APPROX 3" BEHIND MOUNTING SURFACE. ACCESS TO REAR PANEL REQD FOR WIRING AND CALIBRATION.

THERMOTRON CORPORATION
HOLLAND, MICHIGAN 49423

NOM. BOX OUTLINE WIDTH = 6.000"
.250
MOUNTING HOLES EQUALLY SPACED AT EACH CORNER. NO. 6-32 FASTENING HARDWARE RECOMMENDED. USE 5/32 DIA (.156) HOLE TO CLEAR 6-32 SCREW, OR TAP, AS DESIRED.
4 MOUNTING HOLES EQUALLY SPACED WITHIN OUTLINE RECTANGLE ON 4" x 11" CENTERS. NO. 6-32 FASTENING HARDWARE (PAN OR BINDER HEAD SCREWS) RECOMMENDED. USE 5/32 DIA (.156) HOLE TO CLEAR 6-32 SCREW, OR TAP, AS REQUIRED.
NOM. BOX OUTLINE LENGTH = 12.000"

MOUNTING INFORMATION FOR SLOPE GENERATOR (TM) MODEL 013003

NOTE: ONE INCH CLEARANCE REQUIRED EITHER END AND ALONG FRONT EDGE. TOP OF BOX PROTRUDES APPROX 2.5" ABOVE MOUNTING SURFACE. MAINTAIN ACCESS TO TOP OF BOX TO ALLOW REMOVAL OF COVER FOR WIRING AND CALIBRATION.

NO	CHANGES	DATE	BY	CHK'D
	013009 NOTE	3/7/74	G.	

NO	CHANGES	DATE	BY	CHK'D

TOLERANCE	n/a.
SCALE	1 X SIZE
MATERIAL	n/a
FINISH	—
DRAWN BY	GARNER
CHECKED BY	
RELEASED BY	

DESCRIPTION
SLOPE GENERATOR (TM)
MOUNTING INFORMATION

REF: 013008 & 013009

DATE 6 OCT 74
DATE
DATE

470229

(TM) TRADEMARK THERMOTRON CORPORATION

THERMOTRON

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